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MINERAL ZONING IN THE NEW JERSEY–PENNSYLVANIA–VIRGINIA TRIASSIC AREA.

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INTRODUCTION.

THE Triassic mineral deposits played a significant part in the early history of American mining. Copper, iron and lead were obtained in important amounts from its deposits. The Arlington or Schuyler Copper Mine in New Jersey was one of the early copper mines in the United States and is reported to have been the source of considerable wealth to its owners. Other extensive mining took place in the nineteenth century at Somerville, N. J., near Phoenixville, Pa., and in the magnetite deposits of Pennsylvania. The recent production has been from the Cornwall magnetite deposits. Considerable geological work has been done on different parts of the New Jersey–Pennsylvania–Virginia Triassic region, but no attempt has apparently been made to consider or correlate mineralization features of all the area.

The relations of the ore deposits and other mineralization to the main structural features of these rocks, the variation in metals introduced, and the lack of any in different portions of the area, and finally, the fact that the predominant associated igneous rocks are diabase, lend interest to a review of this, in many ways, unique assemblage. The present paper will describe areal changes in the mineralogy of the iron and copper deposits in one of the Triassic areas. Viewed broadly the changes are believed due to tem-

perature-zoning relative to the Triassic erosion surface, and in part to ferric oxide content of wall rock. The areal distribution of the Pennsylvania magnetite deposits is thought to be dependent on major structural relations. Chief attention will be directed to the remarkable zonal relations displayed in the New Jersey-Virginia Triassic area. However, the general geology in the other areas illuminates some of the conceptions advanced, and it will therefore receive attention. The conceptions on the origin of the mineralizing solutions in particular are closely dependent upon the general structure and geologic history of the area. These latter features are markedly different from those found associated with mineralization in the western cordillera of North America. In addition to the abundant information found in the literature, the writer has visited most of the principal mineral localities of the New Jersey-Virginia Triassic area.

Distribution of Triassic Rocks.—The Triassic rocks occur in isolated areas in a belt extending from the northern boundary of South Carolina to the head of the Bay of Fundy, Nova Scotia. Thirteen main separate areas are known, with a number of small outliers which have been separated from the main areas by erosion. In addition numerous diabase dikes of probable Triassic age are widely distributed outside the Triassic sedimentary rocks in the states traversed by the belt.

GENERAL GEOLOGY.[1]

Character of Rocks.—The bulk of the rocks are sedimentary in origin, with lesser amounts of interbedded basaltic lavas, and diabase sills and dikes.

[1] **Powers, S.:** The Acadian Triassic. Jour. Geol. 24: 1–26, 105–122, 254–268, 1916; **Emerson, B. K.:** Geology of Mass. and Rhode Island. U. S. Geol. Surv., Bull. 597, 1917; **Emerson, B. K.:** U. S. Geol. Surv., Holyoke Folio 50, 1898; **Davis, W. M.:** The Triassic Formation of Conn. U. S. Geol. Surv., 18th Ann. Rept.: 2: 1–192, 1898; **Hobbs, W. H.:** The Newark System of the Pomperaug Valley, Conn. U. S. Geol. Surv., 21st Ann. Rept.: 3: 7–160, 1901; **Rice, W. N. and Gregory, H. E.:** Manual of the Geology of Conn. Conn. Geol. Surv., Bull. 6, 1906; **Lewis, J. V.:** The origin and Relations of the Newark Rocks. New Jersey Geol. Surv., Ann. Rept. pp. 99–129, 1906; **Darton, N. H.:** The Relations of the Traps of the Newark System in the New Jersey Region. U. S. Geol. Surv. Bull. 67, 1890; **U. S. Geol. Surv.:** Passaic Folio

The sedimentary rocks are of upper Triassic age (Newark System). They are of continental origin, and consist of sandstones, shales, arkoses, and local conglomerates (fanglomerates). One side of each of the areas is commonly downfaulted relative to the older rocks. On this downfaulted side poorly assorted material is found, chiefly conglomerates, and sandstones, of local derivation. If the older highland on the fault side was composed largely of granitic rocks, these may predominate in the adjacent conglomeratic Triassic rocks. Such local heavy beds of limestone conglomerate in Pennsylvania form the host of some of the magnetite iron-ore mineralization. Beds of black carbonaceous shale are included in the sedimentary rocks in the Connecticut Valley, New Jersey, and southward. Fish remains are found in some of these dark beds. Coal seams are included in the series in Virginia and North Carolina. The common red color of the sedimentary rocks is due to ferric iron compounds that form a coating on the individual grains. For brevity of discussion these are later referred to as ferric oxide.

Igneous Rocks.—The igneous rocks include flows, dikes, sills, stocks (?), and some beds of volcanic tuff and agglomerate. These are prevailingly basaltic in composition. Flows contemporaneous with the sediments predominate in the northern end of the belt, and intrusives in the southern end. Thus are found the extensive lava flows which form the cliffs on the Bay of

No. 157, 1908; Philadelphia Folio No. 162, 1909; Trenton Folio No. 167, 1909; Raritan Folio No. 191, 1914; **Spencer, A. C.:** Magnetite deposits of the Cornwall Type in Penn. U. S. Geol. Surv., Bull. 359, 1908; **Stose, G. W. and Lewis, V. J.:** Triassic Igneous rocks in the Vicinity of Gettysburg, Penn. Bull. Geol. Soc. Amer.: 27: 623–644, 1916; **Jonas, A. I.:** The PreCambrian and Triassic Diabase in Eastern Penn. Bull. Amer. Mus. Nat. Hist.: 37: 173–181, 1917; **Jonas, A. I. and Stose, G. W.:** New Holland Quadrangle. Pa. Geol. Surv., Atlas 178, 1926; **Woodworth, J. B.:** The Atlantic Coast Triassic Coal Field. U. S. Geol. Surv. Ann. Rept. 22: 3: 25–53, maps, 1902; **Prouty, W. F.:** Triassic Deposits of Durham Basin, Relations to other Triassic Areas. Amer. Jour. Sci. (21) 473–490, 1931; **Keith, A.:** Harpers Ferry Folio., U. S. Geol. Surv., Folio 10, 1894; **Clark, W. B. and Mathews, E. B.:** Report on the Physical Features of Maryland. Md. Geol. Surv., Spec. Pub. 6, 1906; **Dorsey, G. E.:** Stratigraphy and Structure of the Newark System in Maryland. Geol. Soc. Amer. Bull. (30) 155–157, 1919; **Shaler, N. S. and Woodworth, J. B.:** Geology of the Richmond Basin, Virginia. U. S. Geol. Surv., 19th Ann. Rept. 385–515, 1899; **Roberts, J. K.:** The Geology of the Virginia Triassic. Va. Geol. Surv., Bull. 29, 1928.

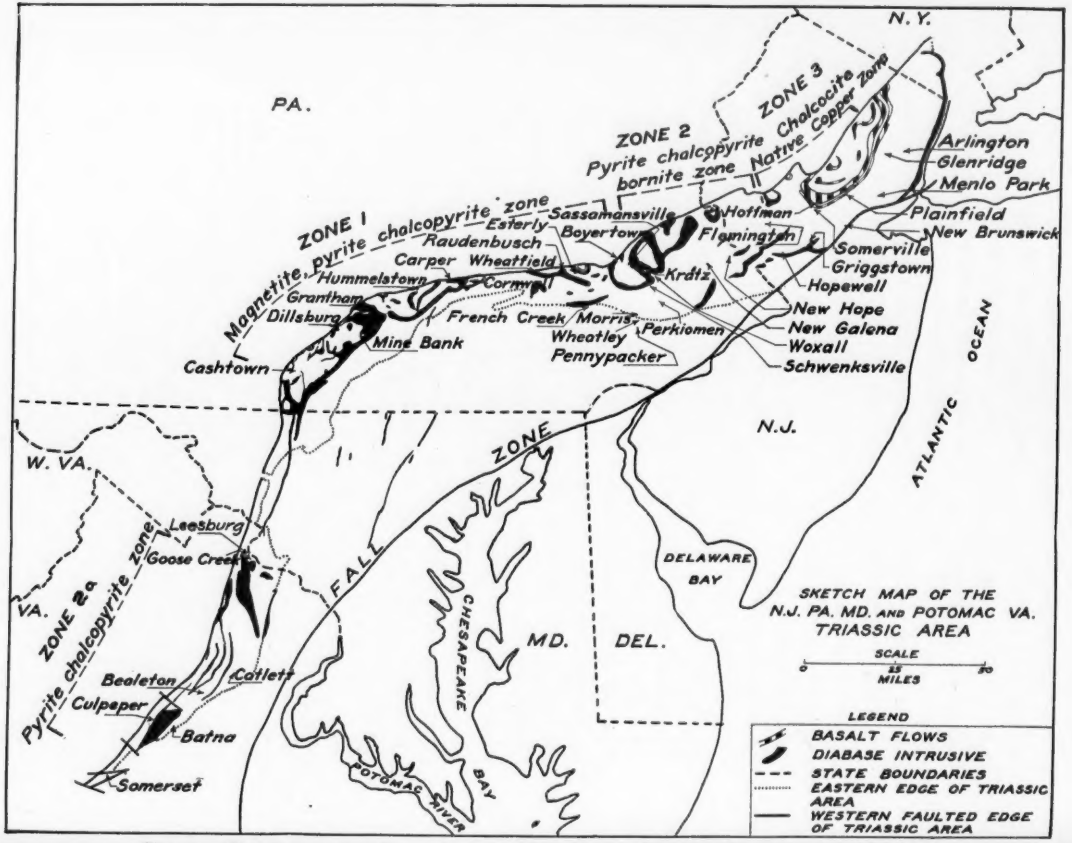

FIG. 1. Sketch map showing zones and relations of mineralization to the Fall Zone.

Fundy Coast of Nova Scotia, the Holyoke sheet in the Connecticut Valley, and large flows in the Watchung Mountains of New Jersey. Important areas of intrusive rocks appear in the belt in Connecticut and from there south to the Deep River area in North Carolina; these predominate over flows from Pennsylvania southward. Two small remnants of flows are reported near the top of the present section in Pennsylvania.

The intrusive sheets are apparently in the main confined to the lower strata, whereas the extrusives are stratigraphically higher. These sheets reach several hundred feet or more in thickness.

Differentiation of the Igneous Rocks.—All general discussions of the igneous rocks have emphasized the uniform basaltic composition from Nova Scotia to North Carolina. In view of the abundant analyses and descriptions in the literature, it will suffice to state here that commonly the minerals present are augite, plagioclase, feldspar, magnetite and a little apatite. Quartz and orthoclase are common in micrographic intergrowths. Olivine and biotite are less common, and small scattered grains of sulphides are almost universally present. Glass is commonly present near the tops and bottoms of the flows.

Some local differentiation and variants have been recognized. Differentiation in a lava flow in Nova Scotia [2] has produced in the last crystallized portion a little above the center of the lava flow, slightly more sodic feldspar than in the upper and lower parts of the flow. The last crystallized portion also showed increasingly low tenor of FeO with respect to MgO. Pyroxene is most abundant in the lower part, especially just below the middle of the flow.

Differentiation in the Palisade diabase sill [3] has produced a mass, the upper portions of which are notably richer in feldspars, the sodic plagioclases and orthoclase preponderating, whereas the lower portions abound in augite and the more calcic plagioclases prevail. Near the base of the sill an olivine-rich layer is present.

[2] Lund, R. J.: Differentiation in the Cape Spencer Flow. Amer. Min. (15), 539–563, 1930.

[3] Lewis, J. V.: Petrography of the Newark Igneous Rocks of New Jersey. N. J. Ann. Rept., Pt. 4, 99–167, 1907.

FIG. 1. Sketch map showing zones and relations of mineralization to the Fall Zone.

Similar differentiation [4] has apparently taken place in the Gettysburg sheet, Pa.

The differentiation has been more pronounced in the sills than in the flows. Both examples have been considered by former writers as mainly due to fractional crystallization with arrangement by gravity. The more advanced stage of differentiation reached by the sills may be accounted for in large part by slower cooling of the intrusive rock.

A different type of local differentiation product is described by Shannon in the diabase at Goose Creek, Virginia.[5] Diabase pegmatite containing a slightly higher percentage of alkalies and silica than the normal diabase is found with albitic pegmatite and aplitic albite dikes. The latter two types of differentiation product show marked increases in silica and sodium. The rocks are hydrothermally altered adjacent to small fractures and a long series of minerals have been deposited in the fractures. The whole assembly of phenomena are regarded by Shannon as being due to crystallization differentiation, which concentrated volatiles, chiefly water. According to Roberts,[6] the diabase at this locality is a part of the Belmont stock. A similar stock near Sterling also contains pegmatites. Small pegmatite dikes are found in the diabase at French Creek, Pa.[7]

In contrast to these local differentiates, are others that formed at some distance below the present surface and which have been intruded as dikes. Some of these show marked compositional differences from the normal diabase. A thin acid dike [8] in the Triassic area near Fair Haven, Connecticut, has been described by Hovey as a keratophyre. A body of felspathic diabase or anorthosite cross-cuts Triassic sediments in the Fairfield quadrangle, Pa.[9]

[4] Stose, G. W. and Lewis, J. V.: *Op cit.*

[5] Shannon, E. V.: The Mineralogy and Petrology of Intrusive Triassic Diabase at Goose Creek, Loudon Co., Va. Proc. U. S. Nat'l Museum, 66: 1–86, 1924.

[6] Roberts, J. K.: *Op. cit.*, pp. 87–88.

[7] Smith, F. F.: Magnetite Deposits of French Creek, Pennsylvania. Penn. Geol. Surv., Bull. M-14, 36–37, 1931.

[8] Hovey, E. O.: Amer. Jour. Sci., 3: 284, 1897.

[9] Stose, G. W. and Lewis, J. V.: *Op. cit.*, p. 635.

Watson and Cline[10] describe a series of dikes in Virginia which are held to be of Triassic age. These dikes include some of normal Triassic diabase, others are nepheline syenite, felsophyre, quartz gabbro, teschenite, and camptonite.

An occurrence of nepheline syenite, hornblende, syenite, mica syenite and hornblende granite associated with Triassic diabase at Brookville, New Jersey, was regarded by Ransome[11] as possibly intrusive but more probably inclusions in the diabase.

N. L. Bowen is reported to have collected specimens from this locality which suggest differentiation of the nepheline syenite and, on a small scale, an intrusive relation toward the gabbro.[12] These dikes strongly suggest that more pronounced and extensive differentiation took place at some distance below the present surface than in the intrusions now exposed by erosion.

Structure.—There is at present some unanimity of opinion on certain features of this controversial problem. Steeply dipping faults of considerable throw separate the Triassic from the older rocks on one side of each area.[13] On the other side the Triassic commonly rests on an erosion surface of the older rocks. The Triassic sedimentary rocks resting on the unconformity dip toward the downfaulted side. Some faults and folds are present within the basins. The evidence indicates that the faulting at the border of the areas was initiated early in the depositional history of the basin and that recurrent movement along the fault planes continued probably until deposition ceased and possibly for some time afterward.

Contact Metamorphism.—An outstanding feature of the contact metamorphism related to the Triassic diabase intrusions is

[10] Watson, T. L. and Cline, J. H.: Petrology of a Series of Igneous Dikes in Central Western Virginia. Bull. Geol. Soc. Amer., 24: 301–334, 1913.

[11] Ransome, F. L.: Amer. Jour. Sci., 8: 417, 1899, also Trenton Folio, p. 9.

[12] Aurousseau, M. and Washington, H. S.: The Nephelite Syenite and Nephelite Porphyry of Beemerville, N. J. Jour. Geol., 30, 573, 1922.

[13] Pirssom and Schuchert: Textbook of Geol., Pt. 2, p. 457, 1924. Longwell, C. R.: Triassic Rocks in Conn. Amer Jour. Sci. (5), vol. 4, pp. 223–236, 1922. Russell, W. L.: Great Triassic Fault of S. Conn. Amer. Jour. Sci. (5), vol. 4, pp. 483–497, 1922. Stose, G. W. and Bascom, F.: Fairfield and Gettysburg Folio, Pa. U. S. Geol. Surv. Folio 225, 1929.

the high-temperature type of minerals commonly formed. The mineralogy suggests definitely higher temperature conditions than the common suite of contact-metamorphic silicates associated with intrusive granitic rocks. Another feature worthy of comment is the fact that of the two main types of intrusives, dikes and sills, the contact metamorphism is almost wholly related to the sills.

Extent of Contact Metamorphism—In New Jersey and Pennsylvania the Triassic shales may be metamorphosed for a distance of several hundred feet from the thick sills, limestone where adjacent, as in Pennsylvania, may also be strongly metamorphosed, but arkose and sandstone may show little effect.[14]

Metamorphism of the shale has produced hornfels, with considerable variety in composition. Feldspar, biotite, cordierite, augite, quartz, hornblende, garnet, spinel, scapolite, epidote, vesuvianite, andalusite, sillimanite, tourmaline and other minerals are present. The mineral assemblage varies in different localities.

The many descriptions of contact-metamorphic ore deposits related to the more salic rocks of the western Cordillera of America disclose few examples with such a high-temperature assemblage of minerals. The explanation of this high-temperature aggregate of minerals is probably found in the higher temperature of intrusion of a magma of diabasic composition as compared with the temperature of intrusion of granitic rocks.[15] Limestones, calcareous shales, and limestone conglomerates form the host rocks for the contact-metamorphic magnetite deposits in Pennsylvania.[16] The contact-metamorphic silicates associated with the magnetite ore are typically fine grained. The minerals

[14] Irving, J. D.: School of Mines Quart. 20, 213–223, 1899. Lewis, J. V.: *Op. cit.*, p. 138–147. Bascom, F. et al.: Geol. Quakerstown, Doylestown District, Pa. and N. J. U. S. Geol. Surv., Bull. 828, 36–37, 1931. Jonas, A. I. and Stose, G. W.: Lancaster Quadrangle, Pa. Top. & Geol. Atlas 168, 52–55, 1930.

[15] Larsen, E.: The Temperature of Magmas. Amer. Min., 14: 81–94, 1929. Schwartz, G. M.: The Contrast in the Effect of Granite and Gabbro Intrusions on the Ely Greenstone. Jour. Geol., 32: 89–128, 1924.

[16] Spencer, A. C.: *Op. cit.* Harder, E. C.: Structure and origin of the magnetite deposits near Dillsburg, York County, Pennsylvania. Econ. Geol., vol. 5: 599–622, 1910. Stose, G. W. and Bascom, F.: *Op. cit.*, p. 19. Smith, L. L.: *Op. cit.*

Note: This MSS. was received while the paper by W. O. Hickok on the Geology of the Cornwall Ore Deposits was in press (Editor).

reported are augite, biotite, actinolite-tremolite, albite, epidote, talc, and some garnet. At Dillsburg [17] garnet is abundant in the baked shale partings. Farther to the southwest of the chief magnetite mineralization along the belt in Pennsylvania, local heavy garnetization has taken place.[18] Large amounts of fine-grained diopside and diopside-garnet rock have been formed by intrusive diabase at Leesburg, Va.[19] A little magnetite is present and is younger than the fine silicates.

PHYSIOGRAPHIC EVIDENCE OF DEPTH OF EROSION IN THE TRIASSIC AREA FROM NEW JERSEY INTO VIRGINIA.

Davis [20] considered that in Northern New Jersey, the Cretaceous sediments at one time covered the Triassic. Evidence in support of this theory is in part the general lack of Triassic fragments in the Cretaceous sediments, and the better adjustment of streams west of the Triassic in the highlands, than in the Triassic itself. Greater length of time for erosion was believed to have given more opportunity for adjustment in the highlands area.

Johnson [21] has given a different explanation of these features. According to this writer, the Cretaceous beds are regarded as having extended not only over the Triassic belt in New Jersey, but on across the highlands as well. South of New Jersey, Cretaceous deposits also extended west over the Appalachians. The erosion surface on which the Cretaceous sediments were laid is termed the Fall Zone peneplane. The remanents of the Fall Zone peneplane, under the present Cretaceous beds of the coast, are highly inclined and are cut at an angle by the later Schooley peneplane. Arching of the Fall Zone peneplane and the Cre-

[17] Harder, E. C.: *Op. cit.*, pp. 618–622.

[18] Stose, G. W. and Bascom, F.: *Op. cit.*, p. 19.

[19] Shannon, E. V.: Mineralogy and Petrography of Triassic Limestone Conglomerate Metamorphosed by Intrusive Diabase at Leesburg, Va. Proc. U. S. Nat'l Mus., 66: 6, 1925.

[20] Davis, W. M.: The Rivers of Northern New Jersey. Geographical Essays, 485–513, 1909.

[21] Johnson, Douglas: Stream Sculpture on the Atlantic coast. Columbia Univ. Press, 1931.

taceous beds preceded the beveling of the Schooley peneplane. In New Jersey,[22] "The angle of slope of the Fall Zone peneplane wherever observed in or near the coastal plain province is such that its projection inland, even with an appreciably decreasing slope, will carry it well above the upland remnants of the later developed Schooley peneplane. This means that in the crystalline highlands a great vertical distance presumably separates the restored portions of the two peneplanes, whereas in the Watchung district, only a few miles west of the intersection of the two surfaces, the vertical distance separating the two must be small." This conception involves greater vertical erosion between Fall Zone Peneplane time and Schooley time some distance west of the intersection of the two peneplanes than near to it.

The southwestern part of the Triassic belt in Pennsylvania trends west away from the present border of the Cretaceous and the intersection of the two peneplanes. It would thus appear that the Triassic rocks were more deeply eroded in southern Pennsylvania than in eastern Pennsylvania and New Jersey—between Fall Zone peneplane time and Schooley time. On southward, in Virginia, the Triassic belt nears the "Fall Zone" again and the total post-Fall Zone peneplane erosion should be less than in the southwestern part of the Triassic belt in Pennsylvania.

A rough estimate may be made of the post-Schooley-Kittatinny erosion. In Northern New Jersey, the remnants of the Schooley peneplane include some of the higher basalt ridges of the Triassic.[23] This gives a maximum of several hundred feet for post-Schooley erosion of the other more deeply eroded Triassic rocks.

In the Gettysburg region in Pennsylvania the difference in elevation between the Schooley peneplane as shown on South Mountain about 4–5 miles west of the Triassic belt and the present Triassic surface is about 800–1,000 feet. In Virginia a difference of 2,500 feet and over is found between the elevation of the Blue Ridge and the present surface of the westernmost part of the Triassic area under consideration. The Blue Ridge here

[22] *Idem*, 87–88.

[23] U. S. Geol. Survey, Folio 191, p. 21, 1914.

is 20–25 miles west of the Triassic area. Since the remnants of the Schooley-Kittatinny peneplane mentioned above lie some distance west of the Triassic areas and probably slope eastward toward the Atlantic, it is obvious that the true figures for post-Schooley erosion must be less in Pennsylvania and much less in Virginia than those given. The general deepening of post-Schooley erosion of the Triassic south from New Jersey into Pennsylvania seems well supported. Whether it is greater or less in the continuation of this Triassic area in Virginia is not apparent from these data.

The diastrophic evidence as shown by the boundary between the Cretaceous and Tertiary stratigraphic units in New Jersey indicates greater erosion to the south in Gloucester County than in the more northerly County of Monmouth.[24] In Monmouth County the Hornerstown Marl (Eocene) rests on a member of the Redbank sand, the youngest division of the Monmouth Group (upper Cretaceous). Southward the Eocene transgresses across the older beds of the Redbank, then across the Navesink marl, and southward in Gloucester county it rests on the still older Mt. Laurel sand of the Monmouth Group. These relations give corroborative evidence that erosion was greater in the southern part of New Jersey than in the north during the interval between upper Cretaceous sedimentation and the deposition of the Eocene.

Another angle of approach may be made, and the total post-Fall Zone peneplane erosion considered at one time.[24a] According to Shaw,[25] well borings and other data show that the erosion surface underneath the Cretaceous sediments slopes about 30 feet to the mile away from the Appalachians. In the District of Columbia it is about 100 feet to the mile. Ashley gives still higher general figures.[26] Since the distances between the Fall Zone and

[24] Cooke, C. W. and Stephenson, L. W.: The Eocene Age of the Supposed Late Upper Cretaceous Greensand Marls of New Jersey. Jour. of Geol., 36, p. 148, 1928.

[24a] This view does not necessitate a similar age for all the surfaces considered as Schooley-Kittatinny in the previous discussion.

[25] Shaw, E. W.: Ages of Appalachian Peneplains. Bull. Geol. Soc. Amer., 29: 582, 1918.

[26] Ashley, G.: Age of the Appalachian Peneplains. Bull. Geol. Soc. Amer., 41: 696, 1930. Darton, N. H. Jour. Geol., 2, 568–587, 1894.

the Triassic area are much less in New Jersey and Virginia than in Pennsylvania the total erosion should be less.[26a] In brief, although the writer can offer no physiographic evidence on the relative amounts of pre-Cretaceous erosion suffered by the New Jersey-Virginia Triassic belt, the post-Fall Zone Peneplane erosional features strongly suggest progressively deeper erosion going southward from New Jersey into Pennsylvania in the belt and less erosion again in the extension of the belt into Virginia. This is in harmony with the evidence afforded by the changing mineralization in New Jersey, Pennsylvania, and Virginia.

MINERALIZATION.

A varied and extremely interesting mineralization is connected with the Triassic areas in eastern North America. The elements introduced include iron, cobalt, nickel, copper, lead, silver, zinc, barium, sulphur, boron, and others. This paper is intended to include only certain features connected with the iron, cobalt, nickel and copper mineralization in one Triassic area, the one which extends from northern New Jersey into Virginia. The lead-silver-zinc-barium veins show features quite distinct from the copper-iron ore, and are not considered in the present paper. They are in faults, and mainly formed by filling open spaces rather than by replacement, and they do not show the close genetic relationship to diabase intrusives and their associated contact-metamorphic zones that is shown by the copper sulphide-iron mineralization. Quartz or barite is usually abundant. Zeolitic mineralization [27] of the type described by Fenner is also not considered.

Origin of the Contact-Metamorphic Magnetite Deposits.—Both the relations of the deposits to the major structural features of the Triassic area, and the relations of the individual deposits to the immediately adjacent rocks, suggest that the magnetite and sulphide forming solutions came from below rather than from the adjacent diabase.

[26a] It does not appear likely that the Fall Zone peneplane would be warped down again before reaching the westernmost Triassic.

[27] Fenner, C. N.: Ann. N. Y. Acad. Sci. 20, Pt. 2, 97–187, 1910.

In brief review, the writer believes that the significant major structural relations are as follows: Within the Triassic area, from the Delaware river southwest to the Maryland border, the diabase intrusives are more prominently developed in the western part of the Triassic area than in the eastern part. The modern stratigraphic studies on the area indicate that faulting was taking place along the western boundary of the area during the deposition of the sediments. The intruding diabase apparently entered along these breaks and formed dikes and sills in the Triassic sedimentary rocks.[28] These intrusions penetrated the sedimentary rocks for variable distances eastward from the faulted area, but usually not as far as the present eastern limits of the area. Although Triassic dikes of diabase which probably came as such from a deep-seated source—the basaltic layer—are found in the older rocks adjacent to the Triassic area, the arrangement of the sills within the area, and the known stratigraphic and faulting history on its western border strongly suggest that the main uprise of magma from depth was in this part. Shales and other rocks have been metamorphosed, particularly adjacent to sills. This metamorphism is not confined near the faulted border zone as are the magnetite deposits. The localization of the metamorphosed rocks adjacent more commonly to sills than to dikes suggests that the solutions which metamorphosed the rocks came from the local intrusives, but tended to rise or migrate upward until trapped by the flat-lying sills or sedimentary rocks.

The magnetite deposits are obviously a more special and localized type of mineralization than are the recrystallized "baked" rocks, in which compared with the magnetite deposits only slight additions of material took place. The magnetite deposits have been found only near the faulted border zone of the Triassic. The deposits at Boyerstown (Table I) are within a mile of the western contact, as also are those of the Esterley mine, the Raudenbusch, the Wheatfield, the Cornwall, the Carper, the Hummelstown (?), the Grantham and the Cashtown mines. The Dillsburg group of mines are 1½ to 2½ miles from the western

[28] Stose, G. W. and Bascom, F.: *Op. cit.*, pp. 10–13.

TABLE I.

PRINCIPAL LOCALITIES WITH THE MINERALS IN APPROXIMATE ORDER OF ABUNDANCE.

Locality	*Chief metallic minerals*
Arlington	Chalcocite, a little bornite and native copper
Glenridge	Chalcocite
Menlo Park	Native copper, minute grains of chalcopyrite & magnetite
Plainfield	No primary ores
New Brunswick (or French Mine)	Native copper
Hoffman	Native copper and chalcocite
Somerville	Native copper, chalcocite and chalcopyrite
Griggstown	Chalcocite, bornite and some specularite, magnetite, chalcopyrite and pyrite
Flemington	Chalcocite, chalcopyrite, bornite
Woxall	Chalcopyrite, magnetite, bornite
Schwenksville	Bornite, chalcopyrite and supergene chalcocite
Kratz	Chalcopyrite, bornite
Sassamansville	(or Brendlinger Mine) Chalcocite, pyrite, chalcopyrite specularite
Boyerstown	Magnetite, pyrite, chalcopyrite, specularite
Esterly	Magnetite
French Creek	Magnetite, pyrite, chalcopyrite
Raudenbusch	Magnetite, pyrrhotite
Wheatfield	Magnetite, pyrite
Cornwall	Magnetite, pyrite, chalcopyrite, specularite
Carper	Magnetite ? Data incomplete
Hummelstown	Magnetite, specularite, pyrite
Grantham	Magnetite ? Data incomplete
Dillsburg	Magnetite, pyrite, chalcopyrite
Minebank	Specularite, magnetite, chalcopyrite
Cashtown	Magnetite
Leesburg	Magnetite, small amount
Goose Creek	Chalcopyrite, pyrite, specularite
Bealeton	Pyrite, chalcopyrite
Culpeper	Specularite and oxidized copper minerals
Batna	Chalcopyrite, pyrite
Somerset	Chalcopyrite, pyrite

The deposits at Hopewell, New Hope, New Galena, Perkiomen, Morris, Wheatley, Pennypacker and Catlett are not discussed in this paper. The reasons for not including them are given elsewhere.

Data taken from:

Lewis, J. W. (N. J.), Ann. Rept. Geol. Survey, N. J., pp. 131–164, 1906. (N. J.), ECON. GEOL. 2, pp. 242–254, 1907.
Wherry, E. T. (Pa.), ECON. GEOL. 3, pp. 726–738, 1908.
Miller, B. L. (Pa.), Geol. Survey, Pa., Bull. M–5, 1924.
Spencer, A. C. (Pa.), U. S. Geol. Surv. Bull. 359, 1908.

Harder, E. C. (Pa.), ECON. GEOL. 5, pp. 599–622, 1910.
Gordon, S. G. (Pa.), Min. of Pa., Phila. Acad. Nat. Sci., 1922.
Stose, G. W. and Bascom, F. (Pa.), U. S. Geol. Surv. Folio 225, 1929.
Bascom, F. Wherry, E. T. et al. (Pa.), U. S. Geol. Surv. Bull. 828, 1931.
Shannon, E. V. (Va.), Proc. U. S. Nat. Mus., vol. 66, Art. 28, 1925.
Roberts, J. K. (Va.), Va. Geol. Surv., Bull. 29, 1928.
Weed, W. H. (Va.), U. S. Geol. Surv. Bull. 455, 1911.

The writer has examined ores and polished sections from a majority of these deposits.

border, and those at the old workings at Minebank—on ores of specular hematite and magnetite—are about 6½ miles from the northwest boundary of the Mesozoic belt. The Jones and Warwick mines in the vicinity of French Creek are both near the southeastern border of the Triassic rocks. The southeastern margin is apparently faulted at this place and intrusive diabase is found along the contact for some distance.

In brief then, looking at the area as a whole, although the diabase appears in considerable amount from the contact eastward or southeastward to distances of ten or twelve miles from the western contact, with much local metamorphism of adjoining rock, the deposits of magnetite are confined mainly to the western fifth of the area, excepting Minebank with its specularite-magnetite mineralization (indicating lower temperature conditions of deposition), and the mines at French Creek, which are on a faulted part of the eastern border. The broad features of distribution of the magnetite deposits are not attributable to the presence or absence of calcareous beds.[29] The detailed stratigraphic work supports this conclusion by showing the presence of calcareous beds in contact with intrusives elsewhere than at the western border. The work of Spencer and Harder has shown that most of the deposits are adjacent or very near to masses of the diabase. This suggests a genetic relationship. In detail the individual deposits are commonly located underneath a shale or a diabase hanging wall, indicating upward movement of the mineralizing solutions.

These features of distribution suggest that some mineralizing

[29] Harder, E. C.: Magnetite Deposits near Dillsburg, Pa. ECON. GEOL., vol. 5, p. 617, 1910. Stose, G. W. and Bascom, F.: *Op. cit.*, pp. 9–10.

solutions came up with the diabase on intrusion. The intrusion or movement of magma, presumably means its transfer to zones of lesser pressure. This lowering of pressure on the magma, or the crystallization of its minerals, released solutions. These solutions in general could not readily escape from the vicinity of the sills, and time was afforded for recrystallization (with some additions of material) of the adjoining rock while they were still present. Where the solutions came from dikes, they moved upward probably to overlying sills or to the surface, and hence did not commonly react strongly with the adjacent wall rock. This explains the wide distribution of baked or metamorphosed rocks near diabase far from the western boundary.

The magnetite deposits where large percental introduction of foreign elements has taken place are believed to have been formed by solutions that came up from depth along a zone of major faulting and intrusion, chiefly in the western part of the Triassic area but also locally along an intrusion and fault zone on the eastern border near French Creek. The solutions are regarded as having moved along openings created during the diabase intrusion, and when they entered a suitable structural trap—frequently underneath a flat-lying shale bed, or diabase sill—they reacted with the wall rock and formed magnetite deposits. The relative distribution of the higher and lower temperature minerals at Cornwall indicates that the diabase intrusives were still hot.[30]

Zonal Mineral Relations.—This Triassic area, which is about 300 miles long, contains copper mineralization at both ends and contact-metamorphic magnetite deposits in the central part, in Pennsylvania (Fig. 1).

Viewed broadly, the amount of copper present in the magnetite deposits probably is of the same order of magnitude as the quantity in the New Jersey copper deposits. From the standpoint of metals, the usual measure of zoning, the ends of the belt contain copper and the central part iron and copper. Cobalt and nickel are also present in the central part, with cobalt in lesser amounts extending over into the copper mineralization of New Jersey.

[30] Callahan, W. H. and Newhouse, W. H.: A Study of the Magnetite Orebody at Cornwall, Pa. ECON. GEOL., vol. 24, pp. 403–411, 1929.

Sulphur increases relative to the copper from the ends toward the central part. Examination of the mineral occurrences and a perusal of the literature has revealed that the zoning is shown with more detail in a gradual change of mineralogy from New Jersey into Pennsylvania.[31] This gradation is shown graphically in Fig. 1. The several zones into which the mineralization has been arbitrarily divided on the map contain, in some deposits, some minerals of the adjoining zone. The bulk of the mineralization is clearly in conformity with the zones outlined on the map, a fact which has been recognized before for part of the area by Wherry.[32] Primary native copper and chalcocite are undoubtedly the chief copper minerals in Zone 3, but minor amounts of bornite are present in ores from the Arlington (Schuyler) and Somerville Mines, as well as in others. In the border part of Zone 2, chalcocite is found, as at the Griggstown and the Flemington mines, but in a large proportion of the mineralized places bornite or chalcopyrite, or both minerals, are present with little if any chalcocite. Specular hematite, and occasional small amounts of magnetite may accompany the copper-iron sulphides. Also some minor copper showings, mostly of oxidized minerals without magnetite, are found in Zone 1. Zone 2, which is north of the magnetite deposits in Pennsylvania, is similar to Zone 2-a lying south of the magnetite deposits, excepting that bornite is present in Zone 2.

Pyrite is most abundant in Zone 1, decreases in relative amount to the other metallic minerals in Zone 2, and is present in Zone 3 in very small amounts, if at all, in most of the deposits. In general, the age relations of the metallic minerals are: iron oxides first, then pyrite followed by chalcopyrite and bornite, then chalcocite. This time sequence of minerals parallels the spatial sequence. The earliest minerals are those more characteristic of the deposits found toward the central part of the area, and the

[31] Lewis, J. V.: Copper Deposits of the New Jersey Triassic. ECON. GEOL., 2: 242–257, 1907; Ann. Rept. N. J. Geol. Surv., 1906. Wherry, E. T.: The Newark Copper Deposits of Southeastern Pennsylvania. ECON. GEOL., 3: 726–738, 1908. Weed, W. H.: Copper Deposits of the Appalachian States. U. S. Geol. Surv., Bull. 455: 92–94, 1911. Roberts, J. K.: The Geology of the Virginia Triassic. Va. Geol. Surv., Bull. 29: 134–136, 1928.

[32] Wherry, E. T.: *Op. cit.*, p. 731.

later ones are those typifying the deposits toward the ends of the area.

That these mineral differences indicate temperature differences in part can hardly be denied. The magnetite deposits were formed at a high temperature, the pyrite, chalcopyrite and specularite deposits north and south of these were deposited at a lower temperature, and those of chalcocite and native copper, at a still lower one. The question arises, as to what geological body or surface this zoning or mineral variation can be ascribed. Ordinarily zoning where found can plausibly be referred to an igneous intrusion such as a stock or small batholith. The general geology of this Triassic area as well as of the others in the eastern United States precludes the hypothesis of a Triassic batholith somewhere at depth underneath the Pennsylvania Triassic region. In addition, the distance of 300 miles from one end of the mineralization to the other does not favor the theory of a stock or larger intrusive body as a focal point or area for mineralization.

The writer believes that the solutions which formed the magnetite and copper deposits came from rock of basaltic composition. The evidence supports the view that they very closely followed in time, the intrusion of basaltic magma into the levels of the Triassic rocks which are now exposed. The deposits in Zones 1 and 2 are practically all in contact-metamorphic zones near diabase intrusives. It is believed that the solutions which formed the magnetite deposits came from the same source as the diabase, namely, from well down toward the basaltic substratum. So far as the evidence goes, the copper deposits in the contact-metamorphic zones could have been formed by solutions that came from the same deep source as those which formed the magnetite deposits. They are practically all closely associated with diabase intrusives or faults, which might afford passageways for solutions. So far as the evidence goes they may also have been derived, as suggested by Lewis, from the larger intrusive masses, such as the Palisade sill and others. Both the magnetite and copper-bearing solutions probably followed the diabase intrusions so closely in time that they must have been derived from a source that had as yet been little changed in composition (by differentia-

tion) from that which is exposed as dikes and sills at the present surface. The evidence at Cornwall is clear, that if the solutions came from depth, the mineralization occurred while the intrusion at that place was still hot. The length of time necessary for the border zone of a relatively small intrusive in the upper levels of the earth's crust to cool to a temperature of one hundred to several hundred degrees centigrade—a temperature appropriate for mineral deposition—is probably short compared with the length of time necessary for any extensive differentiation to take place at depth.

If the solutions that formed the deposits came from some depth, the observed zoning can hardly be relative to the source. The only possibility remaining is that the zoning is relative to the surface that existed in Triassic time. The general geological evidence seems excellent in support of this idea. There appears to be at present no possible way of measuring the amount of post-Triassic erosion which preceded the deposition of the Cretaceous sediments. However, if we accept Johnson's analysis of the physiographic changes which have taken place since then, there is a splendid concordance with the mineralization zoning. The idea of mineral zoning with reference to the Triassic erosion surface was developed independently of any preconceived theory of physiographic change. It is believed to be valid regardless of physiographic theory.

Following the establishment of the zoned mineral series from New Jersey into Pennsylvania, the writer became acquainted with Johnson's ideas on the physiographic development in this region. It was at once seen that his views gave an explanation which correlated remarkably well with the mineralization zoning. At both ends of the area where the Fall Zone approaches the Triassic, and hence where the amount of erosion vertically since Cretaceous sedimentation has been *relatively* small, the mineralization is of lower temperature type than it is farther away from the Fall Zone, as in the Pennsylvania magnetite deposits, where a greater amount of vertical erosion took place. The copper-iron mineralization is roughly similar in Virginia to that which is an approximately equal distance away from the Fall Zone in Pennsyl-

vania. Temperature, varying with reference to a Triassic erosion surface, is regarded as one of the main causal factors but not the only one. The presence of native copper in the series cannot be accounted for solely on a temperature basis. If this were so, native copper should be a more frequent primary constituent in copper-bearing regions. Instead, it is generally found in rocks rich in ferric oxide. The important causal factor in the formation of the native copper is suggested by recent work in the Lake Superior copper region.[33] Much evidence is given to show that the high ferric oxide content of the rocks in the Lake Superior district has been the agent that changed the solutions so that native copper was deposited. The cause of deposition of native copper in the Lake Superior region is held to be as follows:[34]

> The theory of ascending origin assumes that the solutions were such as ordinarily deposit sulphides and were essentially reducing and that if they had encountered rocks of the ordinary composition they would have deposited sulphides. But because these solutions encountered rock with a high content of ferric iron there were chemical changes before precipitation. Ferric iron was reduced, sulphur was oxidized, and native copper was formed.

Of much interest here is the relative increase in quantity of sulphur to copper with depth in the Lake Superior deposits. There is a marked relative increase of sulphur to copper from the ends of the Triassic area toward the magnetite deposits in Pennsylvania. In the Lake Superior region cobalt and nickel appear at depth, also specularite and magnetite. The Triassic red beds are high in ferric oxides. Bleaching is common adjacent to the copper minerals in the New Jersey region. The writer believes that the north-south change in mineralization is accounted for by the two factors, temperature and change of solutions due to ferric oxide. In the central part the solutions migrated shorter distances and deposited the bulk of the minerals at high temperature, whereas in the northern part of the area the solutions mi-

[33] Butler, B. S. and Burbank, W. S.: Copper Deposits of Michigan. U. S. Geol. Surv. Prof. Paper 144, 1929. Broderick, T. M.: Zoning in Michigan Copper Deposits and its Significance. ECON. GEOL., 24: 317–326, 1929.

[34] Butler and Burbank: *Op. cit.*, p. 142.

grated through progressively greater thicknesses of the red beds, reached geothermal levels of lower temperature, cooled and were changed so that native copper and chalcocite were deposited.

CONCLUSIONS.

The contact-metamorphic magnetite deposits in Pennsylvania were formed by solutions that originated at depths—probably from well down toward the basaltic layer. They came from rock or magma of essentially basaltic composition and which had as yet probably undergone but little differentiation from a basaltic type when the solutions were given off. The deposits are areally related to the major faulted portion of the Triassic area, and it is believed that these major faults were the conduits up which the main transfer of basaltic magma from depth to the upper levels of the earth's crust took place. The solutions that formed the magnetite deposits are believed to have followed them very closely in time, but did not travel out eastward from this main zone of intrusion as far as the sill-like intrusive spread. Solutions from these local intrusive bodies reacted with adjoining sedimentary rocks and produced baked or metamorphosed zones. These do not show the bulk additions of material that are present in the more localized magnetite deposits. These magnetite deposits contain copper, and copper mineralization with varying mineralogy extends northward into New Jersey and is found southward in Virginia. The variation in mineralogy is ascribed in part to temperature conditions of deposition which, it is believed, were dependent mainly on the Triassic erosion surface, and only in small amount to the distance from source. Auxiliary to the temperature control in the formation of native copper and possibly also of chalcocite was the influence of the ferric oxide in the Triassic red beds. Evidently both factors were essential.

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THE PROBLEM OF SERPENTINIZATION AND THE ORIGIN OF CERTAIN CHRYSOTILE ASBESTOS TALC AND SOAPSTONE DEPOSITS.

H. H. HESS.

INTRODUCTION.

THE writer has spent three years in the study of the alteration of ultrabasic intrusions and has arrived at certain conclusions which are here presented. These conclusions are concerned with the origin of serpentine, chrysotile asbestos, and talc and soapstone deposits. Most of the work was done on the small ultrabasic intrusions that occur in a narrow belt east of the folded Appalachians from Alabama to Newfoundland. Ultrabasics at the base of the Stillwater Complex in Montana and those associated with the Great Dike of Southern Rhodesia were visited and examined but not studied in detail.

Some one hundred and fifty localities were investigated. It has thus been possible to observe all degrees and types of alterations. In this way a picture of the whole was obtained which could not have been obtained by the study of a single district or small group of districts, or by the study of serpentinization without the talc-soapstone type of alteration, or vice versa.

Bensen [1] outlined the problems with regard to serpentinization and summarized all the available data with regard to these problems in 1918. An attempt will be made in this paper to carry on from where Benson left off. The recent work of Bain,[2]

1 Benson, W. N.: The Origin of Serpentine. A historical and comparative study. Amer. Jour. Sci. (4), vol. 46, pp. 693–731, 1918.

2 Bain, Geo. W.: Chrysotile Asbestos: II, Chrysotile Solutions. ECON. GEOL., vol. 27, pp. 281–296, 1932.

Keith, S. B. and Bain, Geo. W.: Chrysotile Asbestos: I, Chrysotile veins; ECON. GEOL., vol. 27, pp. 169–188, 1932.

Burfoot,[3] Cairnes,[4] Cooke,[5] Foslie,[6] Gillson,[7] and others has been taken into consideration.

SUMMARY OF MAJOR RELATIONSHIPS.

1. Two distinct and genetically unrelated types of alteration have been recognized by the writer. The first is serpentinization and the second, the talc-soapstone type of alteration, will be called steatitization.[8]

2. Many cases of serpentinization without steatitization, or of steatitization without serpentinization, occur.

3. Where the ultrabasic has suffered both types of alteration the serpentinization is always the older of the two.

4. Serpentinization is an autometamorphic alteration. It occurs during the last stages of the same cycle of igneous activity as the intrusion of the ultrabasic. In other words, "the ultrabasic stews in its own juice" as Benson suggested.

5. Steatitization occurs at a later time as a result of the action of dilute hot aqueous solutions from below. It is a hydrothermal alteration.

6. The source of the solutions for this hydrothermal alteration has in many cases been traced to nearby younger acid intrusions. But dilute hot aqueous solutions from any other source should produce the same results. Perhaps acid intrusions are merely the most common source for such solutions at depth.

[3] Burfoot, J. D.: The Origin of Talc and Soapstone Deposits in Virginia. ECON. GEOL., vol. 25, pp. 805–826, 1930.

[4] Cairnes, C. E.: The Serpentine belt of Coquihalla Region, Yale District, British Columbia. Canada Geol. Survey, Summary Report, 1929, Part A, pp. 144–197.

[5] Cooke, H. C.: Asbestos Deposits of the Thetford Area, Quebec. Canada Geol. Survey, Summary Report, 1931, Part D.

[6] Foslie, Steinar: On Antigorite-Serpentines from Ofoten with Fibrous and Columnar Vein Minerals. Norsk Geol. Tids., vol. 12, pp. 219–246, 1931.

[7] Gillson, J. L.: Origin of the Vermont Talc Deposits. ECON. GEOL., vol. 22, pp. 246–287, 1927.

[8] Steatitization may be defined as that process of hydrothermal alteration of an ultrabasic which in its final stages results in the formation of a talcose rock. It may be applied either to the process by which soapstones (steatites) are formed or to the process by which relatively pure concentrations of talc are formed.

STEATITIZATION.

The mineral succession series hornblende, actinolite, chlorite, talc, and carbonate is characteristic of steatitization. Hornblende is the high temperature end member of the series, and talc and carbonate the low temperature end members. If the temperature is sufficiently high at the start of the alteration, hornblende will be the first mineral to form; otherwise any lower temperature member of the series may be the first to form. Similarly, the alteration may stop with any member of the series, provided that the solutions are removed from contact with the ultrabasic before the temperature has fallen sufficiently low for talc and carbonate to form. In all the deposits seen by the writer, the alteration took place with continuously decreasing temperature. No reversals of the mineral series were ever noted.[9] This circumstance might be explained if the solutions were always derived from an intrusion below, in which case the solutions coming from this intrusion might be expected to become progressively cooler as the intrusion and surrounding rocks cooled.

Two distinct types of deposits show the characteristic hornblende, actinolite, chlorite, talc-carbonate series of steatitization. One type is perhaps best represented by such rocks as the Virginia soapstones, where the whole mass of the ultrabasic has been altered through a number of mineral facies with little or no change of chemical composition, the reactions taking place essentially in a closed system. The presence of the solutions merely facilitates the recrystallization of the rock to minerals stable at the temperature obtaining. In the second type of deposit the solutions attack the ultrabasic along its margins and along fractures within it, producing an intense alteration locally but not affecting very much the bulk of the intrusive. Much material may be dissolved from the ultrabasic and deposited farther along. Thus, considerable change in chemical composition occurs in the altered portions of the ultrabasic. The reactions are essentially taking place in an open system. Concentration of pure talc may result from this type of alteration. The Vermont talc deposits

[9] Burfoot mentions one such reversal; *op. cit.*

may be considered as a good example of this type of steatitization.

The Soapstone Type of Steatitization.[10]—In the soapstone type of steatitization practically the whole mass of the ultrabasic is altered. If the alteration runs through the whole range of temperatures, the following sequence of events may be expected to take place: First the original olivine and pyroxene (or serpentine) of the ultrabasic is replaced by an amphibole, green hornblende, if the rock originally had a little plagioclase and thus enough alumina to allow hornblende to form, or actinolite,[11] if the rock was deficient in alumina, as most ultrabasics are. A rock consisting largely of amphibole will be developed. As the alteration continues with decreasing temperature the amphibole changes toward tremolite in composition and the total amount of amphibole decreases, being replaced by chlorite. With sufficient alumina present under favorable conditions this chloritization might continue until a rock consisting almost entirely of chlorite resulted. In the average ultrabasic, talc and carbonate appear considerably before this stage is reached, so that the ultimate end product of this type of steatitization is a soapstone consisting of talc and carbonate with perhaps some relics of chlorite. If the ultrabasic is very low in alumina, talc and carbonate may be found replacing amphibole directly, with little chlorite formed. Figure 2 shows a number of volumetric analyses of thin sections of the ultrabasic at Schuyler, Virginia.[12] Whether talc or carbonate predominates in the final soapstone, probably depends on the CO_2 available. Soapstones rich in talc or in carbonate are found. Fig. 1 gives a summary of the mineral facies developed during this type of steatitization.

Accompanying this alteration there is little change in chemical composition, except for some hydration, until talc and carbonate begin to appear. At this stage, CO_2 begins to take the place of

[10] A detailed study of the soapstones of Schuyler, Virginia, has been made by the writer and is being published separately (Amer. Jour. Sci. (5), *26*, pp. 377–408, 1933), so only a brief outline of the essential features of this type of deposit will be given here.

[11] This amphibole is not true actinolite but is intermediate in composition between hornblende and tremolite. It does, however, contain a large proportion of actinolite molecules.

[12] Made with a Wentworth micrometer stage.

some of the SiO_2 and to a lesser extent Al_2O_3, and there is a loss in H_2O. The amounts of the various other essential constituents of the rock, however, remain virtually unchanged even during this last stage of alteration.[13]

	PICRITE	HORNBLENDE AMPHIBOLITE	ACTINOLITE AMPHIBOLITE	CHLORITE GREENSTONE			STEATITE
PICRITE SUITE	OL PX (PC) MT	HB	ACTIN CHLOR	TREM CHLOR MT	CHLOR MT	CHLOR TALC CARB MT	TALC CARB MT

	PERIDOTITE	ACTINOLITE AMPHIBOLITE		STEATITE
PERIDOTITE SUITE	OL PX	ACTIN	(CHLOR)	TALC CARB MT

FIG. 1. Mineral facies of the ultrabasic suites.

Besides the normal type of alteration described above, there are certain vein-like bodies in the ultrabasic at Schuyler which have suffered a different type of alteration. The total bulk of this type would be very small compared to the bulk of the normal type. These "veins" probably represent the main channelways along which the solutions migrated. The zones immediately bordering the "veins" have undergone considerable change in chemical composition. Solutions migrating relatively rapidly along the channelways may have reacted with the wall rocks. These same solutions diffusing relatively slowly from the channelways into the main mass of the ultrabasic are, after reacting with the walls of the channelways, nearly in equilibrium with the rock of the ultrabasic. Thus, the solutions would produce little change in chemical composition in the bulk of the ultrabasic,

[13] Clear, glassy lenses of quartz were found in the hanging wall above the altered intrusive at Schuyler. These may well represent the SiO_2 lost from the ultrabasics during the last stages of steatitization. No corundum was noted at Schuyler, but the invariable association of corundum and talc in deposits such as those in North Carolina or southeastern Pennsylvania indicates a genetic relation between the two. The corundum in these deposits may be the Al_2O_3 dissolved during the last stages of steatitization and re-deposited. In this case corundum, being associated with talc, would be a relatively low temperature mineral.

but their presence would facilitate recrystallization to minerals stable at whatever temperatures obtained.

The Talc Deposit Type of Steatitization.—The deposits most clearly illustrative of the second type of steatitization are the Vermont talc deposits. These are associated with a line of small ultrabasic intrusions that runs approximately north and south through the center of the State. The intrusions are concordant

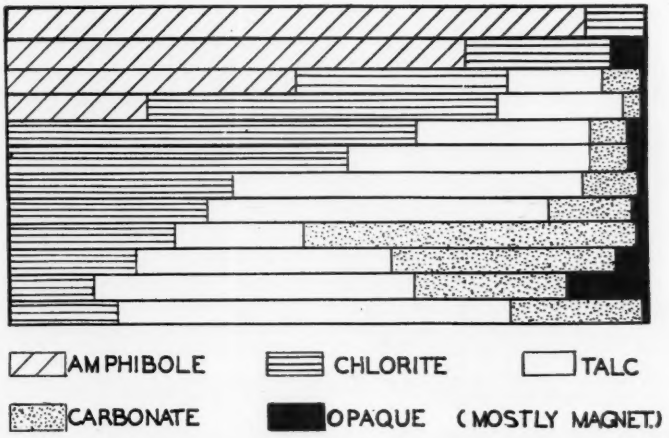

FIG. 2. Volumetric analyses of the soapstones and related ultrabasics from Schuyler, Virginia.

bodies, commonly lenticular in shape, individual lenses varying from 40 feet wide by 100 feet long to four times that size, roughly; but less commonly they occur as pinching and swelling sheets. All of them have been more or less intensely serpentinized. Solutions from below, probably from the Devonian granites and related intrusives, have altered nearly all the ultrabasics to some extent. This alteration is limited in most cases to the contacts of the ultrabasic or fractures traversing it.

The spatial distribution of the alterations, a striking feature of these deposits, is shown in Figs. 3 and 5. The keels of the

ultrabasic lenses have been altered to talc for a thickness, in some cases, of fifteen feet. This alteration to talc narrows up the sides of the lens until it is only a few inches thick as a rule. This relationship was first pointed out to the writer by Bain, with whom he spent a short time in the field during the summer of 1930. The country rock above such a lens is intensely chloritized. A horizontal plane cutting the lens near the top would show a broad aureole of chloritization several times as thick as the lens.

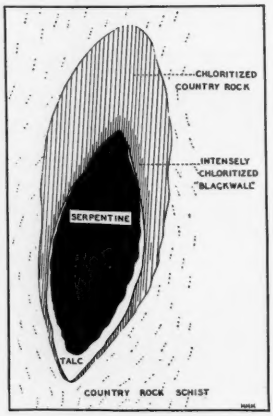

FIG. 3. Diagrammatic vertical section showing distribution of the hydrothermal alterations with respect to a lens of serpentinized ultrabasic.

Farther down the sides of the lens the aureole rapidly becomes narrower. The chloritization is so intense within a few feet of the contact that a rock commonly consisting entirely of chlorite is formed. In some cases, it contains octahedra of magnetite, nodules of carbonate and more rarely epidote. This narrow zone of intense chloritization is locally known as the "blackwall." Fractures within the lens are filled largely by carbonates and there is also some replacement of the ultrabasic by carbonate. In this way, verd antique is formed.

The above description is necessarily generalized. Some talc will be found along with the carbonates; carbonates will be found

in the talc zone; and many of the minor minerals present occasionally or in small amounts have not been considered. The occurrence of actinolite, however, in practically all of the deposits, though often in inconspicuous amounts, is of interest. Acicular crystals in radiating masses are found replacing serpentine along the contacts of the lenses for a few inches. As a rule, the ser-

Photograph by Edward Sampson.

FIG. 4. Quarry at Roxbury, Vermont. The top of a serpentine lens is seen. The talc (white) is only a few inches wide and may be best seen along the upper left hand margin of the serpentine lens.

The dark material beside the talc is "blackwall" chlorite schist. Veins of carbonate may be seen all through the serpentine (verd antique).

pentine matrix has later been replaced by talc and in many cases the talc has replaced the actinolite as well, forming pseudomorphs.

In the great majority of Vermont talc deposits, it appears that the temperature at the start of the alteration was just barely high enough to allow the formation of actinolite. The temperature very soon became too low for actinolite to crystallize, and then chloritization became the dominant process, later to be joined by the formation of talc and carbonate.

The writer is in complete accord with Gillson's conclusions as to the origin of the Vermont talc deposits with one slight modification and one exception. The writer would emphasize to a greater extent the invariable association of the talc with ultrabasic intrusives (excluding talc deposits produced by the alteration of magnesian limestones or dolomites). The overwhelming

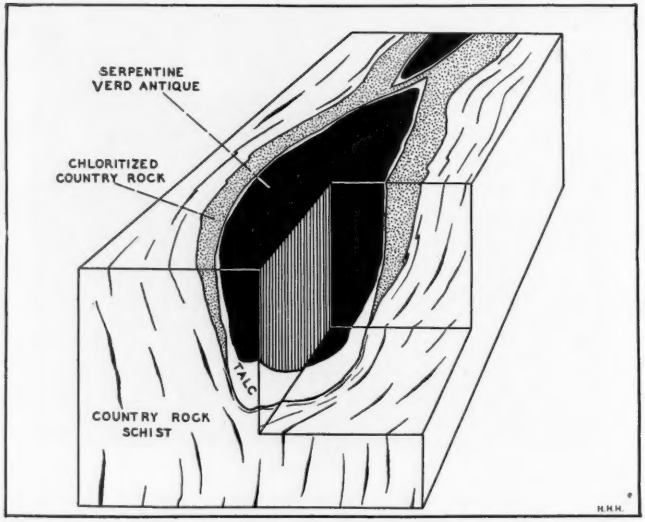

FIG. 5. Block diagram of a typical verd antique-talc occurrence.

proportion of the talc found is a replacement of an ultrabasic, and, in the few cases where it is not, it is a replacement of the intensely chloritized country rock within a few feet or, more commonly, a few inches of the contact of the ultrabasic. Talc deposits as replacements of gneiss and schist entirely apart from ultrabasics do not exist in Vermont.

The writer does not agree with Gillson's statement that "the solutions were hot, alkaline, and were at first siliceous and carried iron and calcium and some aluminum in addition to magnesium. Later the solutions became less siliceous and rich in magnesium."

Inasmuch as the same sequence of minerals and the same type of deposit have developed wherever ultrabasics have suffered steatitization throughout the whole length of the Appalachians, it seems unlikely that solutions of so complex a nature and varying in such a complex manner would in every case have been available. The writer believes that the solutions were exceedingly simple in composition and changed during the alteration only in that they became cooler. They were hot, dilute, aqueous solutions usually carbonate-bearing. These solutions, upon coming in contact with the ultrabasic, extracted iron and, to a less extent, magnesium and the other elements, which they subsequently redeposited as they moved upwards, resulting in the chloritization of the country rock, and later, when the temperature became low enough, in the formation of carbonates. With the formation of chlorite and carbonates above, the keel and side contacts of the lens have been impoverished to a great extent in iron and enriched somewhat in silica, thus accounting for the necessary change in composition from serpentine to talc. In all other respects, the writer agrees with Gillson, particularly as to the hydrothermal nature of the alteration; the paragenesis; the conditions of depth and temperature; the source of the solutions; and that stress was not active during the talc formation.

There remains to be considered the extreme case where a younger acid intrusive lies near or actually cuts the ultrabasic. In such a case, an abundant development of the higher temperature minerals of the series takes place, as would be expected, and the source of the solutions is more obvious.

The talc deposit of the Mineral Products Company, about two miles west of Chester, Vermont, is a good illustration of the steatitization where the acid intrusive is near by. At this place practically the whole mass of the ultrabasic has been altered to talc and carbonate, leaving only occasional serpentine relics. A sheath of biotite schist [14] or biotite actinolite schist from several inches to a few feet thick completely surrounds the deposit. This sheath represents approximately the original contact of the ultra-

[14] This biotite rock is called "blackwall," just as is the intensely chloritized country rock which surrounds the normal type of talc deposit.

basic with the country rock. Horses of serpentine, or serpentine replaced by radiating crystals of actinolite, lie within the talc-carbonate mass. The writer observed stringers of black tourmaline cutting one of the horses, which gives further proof that the acid intrusives were the source of the solutions producing the alterations.

At the Holden soapstone quarry, three miles southeast of Chester, acid dikes actually cut the ultrabasic. At this occurrence there is a series of small lenses, each about 18 feet wide by 40 feet long. These lenses are completely altered to soapstone except for a sheath of biotite-actinolite rock two or three feet thick which

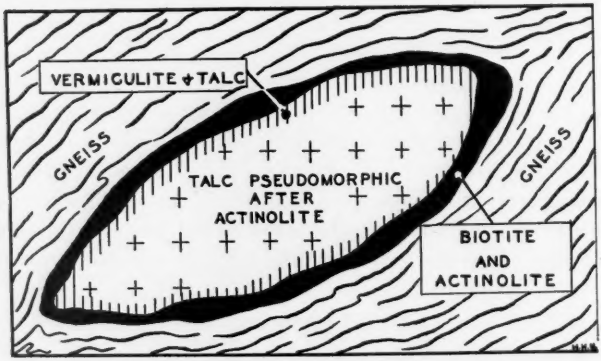

FIG. 6. Diagrammatic sketch of a lens (about 40 feet long) of altered ultrabasic. Holden soapstone quarry south of Chester, Vermont.

encases them (Fig. 6). The soapstone, which now consists largely of talc, some chlorite and a little carbonate, has a texture made up of radiating clumps of acicular crystals, pseudomorphs after actinolite. On the dump, large blocks of ultrabasic altered to a rock consisting almost entirely of green hornblende were found. Unfortunately, their original position in the quarried-out portion of the deposit could not be ascertained. Thus, it appears that the original ultrabasic, probably a serpentine, was largely replaced by actinolite in the early stages of the alteration and certain parts of it were even altered to hornblende, the highest

temperature mineral of the series. The proximity of acid intrusions results in the extensive formation of the higher temperature minerals of the series characteristic of steatitization. These minerals were absent or present in inconspicuous amounts in the common type of talc deposit where acid intrusions are farther away and the temperatures obtaining lower. The gradation from the common type of talc deposit, the origin of which is somewhat obscure, to the extreme type, where the origin is more obvious, serves to clarify the whole process of the formation of these deposits (Table 1).

TABLE I.

Acid Intrusives Distant.		Acid Intrusives Near-by.	Acid Intrusive Cuts Ultrabasic.	
Common Type Talc Deposit.	Virginia Soapstones.	Mineral Products Co. Quarry near Chester, Vt.	Holden Soapstone Quarry South of Chester, Vt.	N. C. Corundum Deposits.
	Hb (light colored)	(black Tourm.)	Hb (green)	En.
(Actin)	Actin.	Actin.	Actin.	Actin.
	Trem.	Bi	Bi and Verm.	Verm.
Chlor.	Chlor.	Chlor.	Chlor.	Chlor.
				Corundum
Talc	Talc	Talc	Talc	Talc
Carb.	Carb.	Carb.	Carb.	Carb.

Larsen [15] gives a description of hydrothermal alteration along the contacts of a small acid dike in serpentine at Brinton's quarry near West Chester, Penna. Here talc, vermiculite, anthophyllite, tremolite, and a little tourmaline are found in bands paralleling the contacts of the dike and also in veins extending into the serpentine. Pratt and Lewis,[16] in their descriptions of the North Carolina corundum deposits, give many examples of steatitization of a similar nature. In these deposits enstatite, actinolite,

[15] Larsen, Esper S.: A Hydrothermal Origin of Corundum and Albitite Bodies. ECON. GEOL., vol. 23, pp. 398–433, 1928.

[16] Pratt, J. H. and Lewis, J. V.: Corundum and Peridotites of Western No. Carolina. Geol. Survey of No. Car., Mem. 1, 1905.

chlorite, vermiculite, and talc are characteristic minerals. They occur as alterations along the contacts of ultrabasics, as veins in ultrabasics, or along the contacts of albitite dikes in the ultrabasics.

In the deposits where acid intrusions are close to or cut the ultrabasic, certain minerals develop in addition to, or instead of, the characteristic series as given in this paper. By far the most common of these minerals is biotite or its hydrated equivalent, vermiculite. It is a hybrid mineral; instead of being composed of elements derived from the ultrabasic as are the minerals of the characteristic series, it derives its potassium from the acid intrusive and its magnesium from the ultrabasic. Enstatite and anthophyllite may, in some cases, appear as the high-temperature members of the series. Black tourmaline is commonly introduced by the solutions from the acid intrusive, and corundum may accompany talc as a by-product of the alteration.

Source of the Solutions.—In the instances previously mentioned, the source of the solutions producing steatitization is clearly the acid intrusives. In the great majority of deposits where known acid intrusives are far away or perhaps not exposed at all, and only the lower temperature minerals of the series have formed, the source of the solutions is not obvious. In a general way there is a correlation between the presence of granite intrusions in the region and steatitization. That is, steatitization is more prevalent in those regions where there are known to be younger granites. It seems likely, all evidence considered, that the source of the solutions was acid intrusives in most, if not in all, cases of steatitization. Since the composition of the solutions plays so small a part in the process, however, dilute hot aqueous solutions from any other source would produce exactly the same results. Sources for such solutions other than from acid intrusives are, perhaps, not common in depth.

Soapstone Type of Alteration vs. the Talc Deposit Type.—Keith and others have expressed the opinion that soapstones were the result of the alteration of pyroxenites, whereas talc deposits resulted from the alteration of peridotites. The controlling

factor was supposed to be composition. Though the fact is correct, that pyroxenites usually alter to soapstone and peridotites to talc, the reason seems to be the *texture* and not the composition. Massive serpentinized peridotites or dunites do not readily allow the migration of solutions through them; but a pyroxenite, which is not so susceptible to serpentinization, will allow migration of solutions to a certain extent along the boundaries of its constituent grains. Thus, granular ultrabasics, such as pyroxenites, unserpentinized peridotites, hornblendites, etc., will alter to soapstones. Serpentinized ultrabasics will become intensely altered along their margins to pure talc in many instances, whereas their interior portions will not be altered except along fractures (thus forming verd antique). An exception to this generalization is worthy of mention; that is, where alteration of a serpentine has taken place at very high temperatures, it may be completely recrystallized as a hornblende or actinolite rock. It thus secondarily becomes granular and it will, if alteration continues to lower temperatures, become a soapstone. A sequence of events exactly like this has occurred at the Holden soapstone quarry described above. Here the original ultrabasic was almost certainly a serpentine. It was replaced to a large extent by radiating crystals of actinolite, which, in turn, were replaced by chlorite and then talc and a little carbonate. The resulting rock is a soapstone composed mostly of pseudomorphs of the younger minerals after actinolite.

Serpentinization and Steatitization.—The evidence is absolutely conclusive that steatitization is always younger than serpentinization and unrelated to it in any way. Minerals formed during steatitization may always be found replacing serpentine, but serpentine never replaces any of these minerals.

With steatitization and the minerals related to it definitely out of the way, the problem of serpentinization may be studied in a new light devoid of much of the confusion which has hitherto hindered the investigation.

SERPENTINIZATION.

Certain facts relating to the process of serpentinization must be explained if a satisfactory theory of serpentinization is to be formulated. These facts are listed and discussed below.

1. The apparent lack of a volume change during serpentinization.
2. The lack of a relation between the distribution of serpentinization and the borders of the ultrabasic.
3. The apparent immobility of the serpentinizing solutions. Serpentine and chrysotile asbestos veins remain within the ultrabasic.
4. The lack of minerals other than serpentine, magnetite, and rarely chromite, which develop during serpentinization, excepting minerals which occur in quantitatively insignificant amounts.
5. In positive cases of hydrothermal alteration of a rock of ultrabasic composition a chlorite will develop but not serpentine.
6. Silica plus water must be added to an unserpentinized dunite or normal peridotite (consisting of olivine and subordinate pyroxene) to change the chemical composition to serpentine.

1. *Lack of Volume Change.*—Current theories of serpentinization either involve huge volume increases (ranging from 24% to 72%) or the extraction of a vast amount of material by solutions and its redeposition as carbonates above. Field evidence shows that no large volume change has occurred. Many highly serpentinized ultrabasics do not have carbonates associated with them. Where large amounts of carbonates associated with serpentines were seen by the writer, they were not related to serpentinization, but to the much younger period of alteration, the steatitization. Serpentinization neither involves huge volume increases nor the extraction of a vast amount of material to avoid in part such a volume increase.

2. *Distribution of Serpentinization.*—In many cases, serpentinization is more or less evenly distributed throughout a given ultrabasic. Harvie made a detailed study of the serpentines around Thetford, Quebec. Cooke quotes him as finding that the serpentinization was fairly uniformly distributed throughout the entire mass of the ultrabasic. The writer has found that where serpentinization is not evenly distributed, it generally has a haphazard arrangement unrelated to the borders of the ultrabasic.

A few cases have been noted in the literature where serpentinization was more intense at the borders than at the middle of the ultrabasic, but no case could be found where serpentinization was more intense along the footwall side of these than along the hanging wall. In the Urals many occurrences of ultrabasics consist of dunitic cores with pyroxenitic borders. In these, the dunite is most intensely serpentinized along its contact with the pyroxenite. Summing up, it may be said that serpentinization in most cases is either evenly distributed throughout the ultrabasic or it has a haphazard distribution unrelated to borders of the ultrabasic; but in a few cases serpentinization increases outwards from the core of the ultrabasic. In the case of steatitization, there is invariably a relation between its distribution and the footwall, keel, or border of the ultrabasic. The distribution is such that there can be no doubt that the solutions producing the alterations came from without and generally from below; whereas the distribution of serpentinization is such that whatever produced it appears to come from within, rather than from without, the ultrabasic. This is one line of evidence indicating the autometamorphic nature of serpentinization.

3. *Immobility of the Serpentinizing Solutions.*—Serpentine and chrysotile asbestos veins remain within the ultrabasic.[17] The old theory[18] that the asbestos veins were recrystallizations or replacements of the wall rock (ultrabasic) along a fissure, fitted well with the fact that the asbestos veins always remained within the ultrabasic. The recent work of Keith and Bain shows conclusively that the asbestos veins are fissure fillings, and replacement and recrystallization played very minor rôles in the vein formation. Thus, whatever filled the fissures to form the veins of ordinary serpentine or chrysotile asbestos must have been exceedingly immobile and could hardly have been a dilute aqueous or gaseous solution.

[17] The writer examined the contacts of the ultrabasics in the Thetford district wherever exposed. Along the footwall contact of the old Federal Mine asbestos veinlets were found extending across the contact for a distance of about eight inches into the schists. This was the only case where such an occurrence was noted.

[18] Dresser, J. A.: Serpentine and Associated Rocks of Southern Quebec. Geol. Survey of Canada, Mem. 22, 1913.

4. *Lack of Minerals Other Than Serpentine, Magnetite and rarely Chromite, which develop during serpentinization.*—One of the most characteristic features of serpentinization is that even though 75 per cent. or more of the ultrabasic is serpentinized, in many cases no minerals other than the three mentioned above have been formed. Rarely, minute amounts of such minerals as magnesite or brucite occur as films on joint planes, but even these minerals, present in insignificant amounts, may be unrelated to serpentinization. Quartz veinlets seem to be associated with serpentinization in a few occurrences. Certain acid segregates within the ultrabasic, albitites mostly, may be, together with the minerals associated with them, of very nearly the same age as serpentinization.[19] In most occurrences of ultrabasics such acid segregates are entirely absent; therefore, they are not an integral part of the process of serpentinization, though they may perhaps offer some clue as to the nature of the residual solutions of the ultrabasic intrusive. In general, typical hydrothermal minerals are practically lacking in serpentinization.

5. *Hydrothermal Alteration of an Ultrabasic Results in Formation of Chlorite but not Serpentine.*—A large number, perhaps fifty, hydrothermally altered (steatitized) ultrabasics were examined and in every case a chlorite,[20] not serpentine, was developed. Hydrothermal alteration of magnesian limestones or dolomites may result in the formation of serpentine, but these rocks do not contain the Fe and Al necessary to make up the chlorite molecule. In ultrabasic igneous rocks where some Fe and Al are available, a chlorite seems to be the mineral which will develop under hydrothermal conditions, but never the Fe- and

[19] The "white dikes" or albitites in ultrabasics in themselves offer a large and complex problem which will have to be avoided at this time. It appears that several quite diverse processes all result in the formation of these soda-rich "white dikes." Some are probably true acid segregates, some appear to be altered siliceous xenoliths, and some are perhaps granite pegmatites which have undergone a peculiar type of modification where they cut ultrabasics.

[20] Serpentine is considered by many mineralogists to be the end member of the "chlorite series." It is the Mg-rich, Fe- and Al-free end of the series. It may be distinguished from the rest of the series by the fact that it is non-pleochroic and nearly colorless in thin section; whereas the rest of the series, called the "chlorites" in this paper, are usually colored, pleochroic, and have higher indices of refraction.

Al-poor end member of the series, serpentine. That chlorite, rather than serpentine, develops under hydrothermal conditions cannot be a result of some difference of either temperature or pressure conditions, because steatitization occurs over a range of temperatures and pressures which must include the temperature and pressure range for the formation of serpentine (Fig. 8). Inasmuch as serpentinization and steatitization are commonly found together in the same rock, the composition of the rock cannot be a factor. Thus, by elimination, the only remaining factor that could control the formation of serpentine is the composition of the solutions producing the change. What must be the nature of these solutions? Under No. 3 it was found that they were immobile, under No. 4 that they did not produce typical hydrothermal minerals, and under No. 5 that they differed from known hydrothermal solutions in their effects.

6. *Serpentinization Involves Adding Water and Silica to a Rock of Peridotitic or Dunitic Composition.*—In previous studies of serpentinization a number of equations are given to account for the chemical changes involved in the process. The four equations given below summarized the various reactions that have been suggested:

(1) $\underset{\text{Forsterite}}{2Mg_2SiO_4} + CO_2 + 2H_2O \rightarrow \underset{\text{Serpentine}}{H_4Mg_3Si_2O_9} + \underset{\text{Magnesite}}{MgCO_3}$

(2) $\underset{\text{Forsterite}}{3Mg_2SiO_4} + SiO_2 + 4H_2O \rightarrow \underset{\text{Serpentine}}{H_4Mg_3Si_2O_9}$

(3) $\underset{\text{Forsterite}}{Mg_2SiO_4} + \underset{\text{Enstatite}}{MgSiO_3} + 2H_2O \rightarrow \underset{\text{Serpentine}}{H_4Mg_3Si_2O_9}$

(4) $\underset{\text{Fe-bearing Forsterite}}{3Mg_3FeSi_2O_8} + 6H_2O + O \rightarrow \underset{\text{Serpentine}}{H_4Mg_3Si_2O_9} + \underset{\text{Magnetite}}{Fe_3O_4}$

Reaction (1) has found the most favor in the recent literature because, by the extraction of the carbonate formed and its redeposition above, serpentinization is accomplished with the least volume increase (24 per cent.). The extensive carbonates associated with certain serpentinized ultrabasics were pointed out by the proponents of this hypothesis as proof of their contention.

The writer does not believe that this reaction has occurred. In many occurrences of serpentinized ultrabasics, such carbonates are entirely lacking. Many serpentinized ultrabasics have been examined by the writer where carbonates are present, but in every case these carbonates are not related to the serpentinization, but to the much younger steatitization.

The writer believes that reaction (2) accounts for practically all of the serpentine formed and that reactions (3) and (4) contribute a small fraction of the serpentine. Since pyroxene is absent from pure dunites and present in subordinate amounts in most peridotites, the amount of serpentine derived from reaction (3) is necessarily small. Reaction (4) is also limited by the small amount of iron in most ultrabasics and the fact that even a part of that remains in the serpentine molecule. Where the oxygen comes from is somewhat of a problem. That some oxygen is available and reaction (4) does take place to a certain extent is indicated by the fact that serpentinized ultrabasics uniformly have a higher Fe_2O_3/FeO ratio than unserpentinized ultrabasics, as can be seen by comparing a large number of analyses of both types (particularly well shown by Duparc's analyses of the ultrabasics of the Urals).

A THEORY OF SERPENTINIZATION.

The writer concludes that serpentinization is an autometamorphic reaction, because (1) its distribution rarely shows a relation to the borders of the ultrabasic in strong contrast to the steatitization type of alteration; (2) field evidence indicates that it occurs during the same cycle of igneous activity as the intrusion of the ultrabasic itself; (3) it always definitely precedes steatitization (hydrothermal alteration). Furthermore, the even distribution of serpentinization in many ultrabasics indicates that it was not only autometamorphic but largely deuteric in the most restricted sense (Sederholm's definition). Cores of olivine uniformly distributed, and about equally corroded, are commonly found in partially serpentinized ultrabasics. This points toward the attack of the olivine grains by a residual liquid present in the

interstices between the grains rather than attack by solutions concentrated in more widely spaced fissures or channelways.

Assuming serpentinization to be an autometamorphic alteration, one cannot, as has been done, compute the volume of dry unserpentinized peridotite, alter it to serpentine by addition of silica plus water, and then compute the volume of serpentine resulting, thus finding the volume has swelled tremendously. If serpentinization is autometamorphic, the magmatic residuum that produced the alteration must have been contained within the volume of the original ultrabasic intrusive. A calculation made on this basis resulted in finding that a slight *volume decrease* should occur during serpentinization (5 per cent. if the ultrabasic were completely serpentinized, which is rarely the case). A slight volume decrease is quite in keeping with the field evidence. It would allow the opening of many small fissures, thus permitting the formation of veinlets of ordinary serpentine or more rarely of chrysotile asbestos, which are commonly present in serpentinized ultrabasics.

$$3Mg_2SiO_4 + H_4SiO_4.2H_2O \rightarrow 2H_4Mg_3Si_2O_9$$

Specific Volumes $3(43.8) + (61)^* + (36)^* \rightarrow 2(108.2)$

$$228.4 \rightarrow 216.4$$

Volume decrease 12, or approximately 5 per cent.

The chemistry of such an alteration as suggested in the preceding paragraphs may now be considered. The Bowen-Andersen equilibrium diagram for forsterite and silica must explain to a large extent what happens in the early stages of the crystallization of the ultrabasic. Olivine crystallizes until the peritectic is reached; and then, if equilibrium conditions are maintained, pyroxene will crystallize and the residual liquid will react with the already crystallized olivine to form pyroxene. The presence of some water, perhaps 10 per cent., a third component in the system, might be expected to lower the temperature of final consolidation very considerably. At the lower temperature, some combination of the silica and water might take place, which in turn might react with the olivine to form serpentine rather than pyroxene,

* Closest approximation available for S. V. of $H_4SiO_4.2H_2O$.

and serpentine might also crystallize directly from the residual liquid at the same time. In the absence of experimental data on the MgO–SiO_2–H_2O system, however, what actually does happen is merely a matter of speculation. An hypothesis such as the one suggested above would be in accord with the petrographic evidence.

As mentioned before, serpentinization might be expected to result in a slight volume decrease. This would allow small fis-

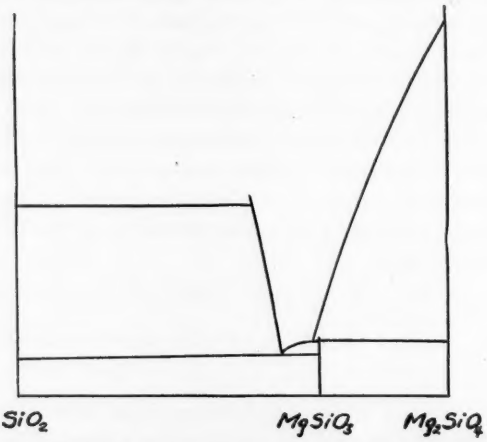

FIG. 7. Equilibrium diagram after Bowen and Andersen.

sures to open in the rock, now practically completely solidified, and these fissures could then be filled with the small amount of residual liquid still remaining. In this manner, veins of ordinary serpentine or occasionally chrysotile asbestos could be formed.

The residual liquid would not be a highly aqueous solution (hydrothermal solution), but rather a highly siliceous solution containing relatively very much less water. Unlike a hydrothermal solution, it is immobile, incapable of moving from the ultrabasic into the slightly cooler country rock, and it does not produce any typically "hydrothermal" minerals. To distinguish the type of solution which the residual liquid must be, from the nor-

mal hydrothermal type of solution, the term "hypohydrous" solution is here suggested, meaning *containing less water* than the hydrothermal type.

Hydrothermal and hypohydrous alterations occur under approximately the same sort of temperature and pressure conditions, although the hypohydrous type is probably more limited in its temperature range than the hydrothermal, unless serpentine

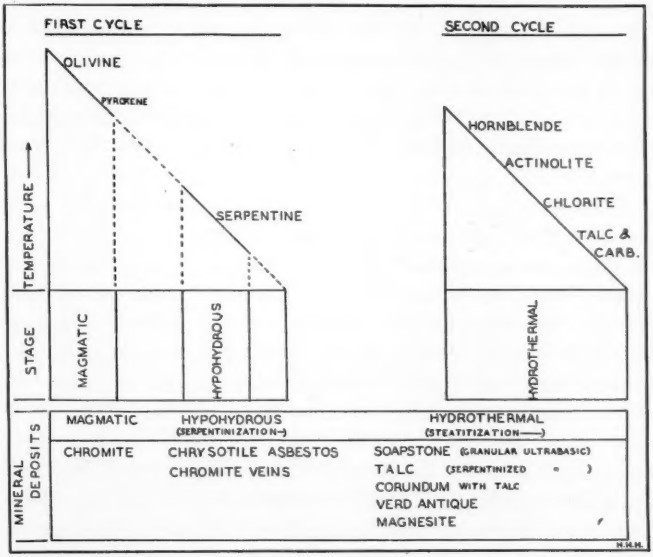

FIG. 8. Diagram showing mineral succession for both the cycle of pyrogenetic and hypothermal crystallization and the later cycle of hydrothermal alteration with decreasing temperature.

may form over a wide range of temperatures, which does not seem likely. Since serpentine is usually considered a member of the chlorite group, its temperature of formation might be supposed to correspond roughly to the temperature of formation of the chlorite in the hornblende-actinolite-chlorite-talc and carbonate series of hydrothermal alteration. The fact that some

serpentines show certain metacolloidal features points toward a relatively moderate temperature of formation.

Certain occurrences of chromite in veins such as those described by Sampson [21] may also belong to the hypohydrous type, rather than the hydrothermal. They are limited to the bulk of the ultrabasic and are associated with serpentine but not with any of the typical hydrothermal minerals.

Source of the Water for Serpentinization.—Though it seems necessary at this time to offer some suggestion as to the source of the water for serpentinization, the writer wishes, before doing so, to point out that the facts of serpentinization presented above seem well established, and their validity is completely independent of the ensuing speculation as to where the water may have come from.

If serpentinization is an autometamorphic alteration, the water must either (1) have been an original constituent of the magma, or (2) have been picked up by the magma from the rocks with which it came in contact during its intrusion. The first of these hypotheses seems unlikely because basic as well as ultrabasic intrusions during their injection and subsequent crystallization produce very little contact metamorphism as a rule (beyond those effects directly due to heat), and are, therefore, thought to contain little water and other volatiles which would cause such metamorphism. Considering the second hypothesis, deep-seated basic intrusions injected into water-bearing country rocks might have, and almost inevitably would have in some cases, a lower vapor pressure than the wall rocks for the temperature obtaining. If this were the case the magma would absorb water from the surrounding rocks. The absence of contact metamorphism around basic intrusives favors the hypothesis that the solutions were moving rather from the country rocks into the magma than vice versa. In contrast to the basic intrusions, the acid intrusions, enriched in volatiles, might be expected to have a higher vapor pressure than the surrounding rocks, and the resulting outward

[21] Sampson, Edward: May Chromite Crystallize Late? ECON. GEOL., vol. 24, pp. 632–645, 1929. Varieties of Chromite Deposits. ECON. GEOL., vol. 26, pp. 833–839.

movements of solutions would produce the extensive contact metamorphism associated with these rocks.

Serpentinized ultrabasics are deep-seated intrusions and almost invariably occur in the belts of folded, metamorphosed, geosynclinal sediments. Such country rocks would be likely to contain some water. An ultrabasic intrusive moving through them would absorb water from them until the vapor pressure of the magma and country rock was the same. The typical serpentinized ultrabasic is a small lenticular intrusion and in most cases is only partially serpentinized, so the total amount of water needed is not large.

Goranson's [22] experimental work has shown the order of magnitude of the solubility of water in silicate melts and the variation in solubility with temperature and pressure. A speculative interpolation from Goranson's data for granitic melts seems to indicate that serpentinization must be a deep seated process and even then the solubility of water in the ultrabasic must be greater than in granite melts. Serpentinization must require about 10 per cent. water in the magma.

Acknowledgments.

The writer desires to express his appreciation to Prof. Edward Sampson and Prof. Arthur F. Buddington for their advice and encouragement throughout the course of this investigation. To the many geologists who aided in the field work, especially to Dr. J. W. Peoples, the writer gratefully acknowledges his indebtedness.

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[22] Goranson, R. W.: The Solubility of Water in Granite Magmas. Amer. Jour. Sci., vol. 22, pp. 481–502, 1931; Some Notes on the Melting of Granite. *Idem*, vol. 23, pp. 227–235, 1932.

MAGNETITE ORES OF NORTHERN NEW JERSEY.

LAURENCE L. SMITH.

ABSTRACT.

Most of the large magnetite ore bodies of the Highlands of northern New Jersey are lens or pod-shaped, and have sharply defined contacts which conform to the foliation of the country rock. Structural and microscopic evidence indicates that these deposits were emplaced by displacement as well as replacement of the enclosing rocks. The ore solutions were end-phase aqueo-igneous differentiates of the same magma from which the granitic gneisses of the area were derived. Deposition of the ore was preceded by the injection of pegmatites and followed by hydrothermal solutions. These processes were continuous and overlapping. The contact zone between a well foliated gneiss and a later intrusive is believed to have afforded a structural weakness which in most places controlled the loci of ore deposition.

LOCATION AND TYPES OF ORE BODIES.

THE ore bodies described in this paper occur in the New Jersey Highlands, a belt from ten to twenty-five miles in width, extending across the north end of the state. Within this area over three hundred mines and prospects have been worked at different times in the past. Of this number about forty have produced at least 100,000 tons each, and several much over that amount. All these mines and prospects have been grouped in belts and described by Bayley.[1]

The magnetite ore bodies are of four types: (1) Replacements of limestone, (2) irregular masses of magnetite in gneiss, (3) disseminated ores in gneiss, and (4) lens or pod-shaped bodies enclosed in gneiss. Nearly all the large ore bodies are of the last type, and it is with these that this paper is mostly concerned.

[1] Bayley, W. S.: Iron Mines and Mining in New Jersey. Geological Survey of New Jersey, Final Report Series, vol. 7, pp. 1–499, 1910. Bayley's work is the most comprehensive study of the iron mines of New Jersey.

Three or four large ore bodies, one of which is worked at present, are of the third type. These will also be briefly considered in this paper. The smaller ore deposits in gneiss, some of which have been but mere prospects, are of the second type. This type and the deposits in limestones are not discussed here.

Only a few mines have been accessible in the last few years. These are the Scrub Oaks mine, two miles west of Dover, the Mount Hope and the Richard mines north of Dover, the Ringwood mine near Ringwood, and the Washington mine near Oxford, New Jersey. The Scrub Oaks deposit is a disseminated ore, the others are lenticular bodies and similar to the majority of the many large deposits formerly worked in the Highlands area.

Most of the detailed work of this investigation was done at the Washington mine. The Washington vein is the most southerly of several more or less parallel ore bodies just south of Oxford, which together constitute the Oxford group. This is the most southwesterly of any of the important groups of mines in the Highlands area. According to Bayley,[2] a charcoal furnace was erected at Oxford in 1742. Since that date the Oxford mines have been among the State's largest producers of iron ore. The individual veins have been named and worked at various times by different companies. In recent years all the production has come from the Washington vein which is operated by the Allan Wood Mining Company.

The writer spent several weeks at the Oxford mines in the summers of 1931 and 1932, and also examined many of the abandoned mines throughout the Highlands area. Mr. Carl Loux, superintendent of the Washington mine, was of valuable assistance in the field and in the mine. The Allan Wood Mining Company kindly permitted publication of this paper.

GENERAL GEOLOGY AND STRUCTURE OF THE HIGHLANDS.

With the exception of a few occurrences in limestones, all the magnetite ore bodies of the Highlands area are enclosed in pre-

[2] Bayley, W. S.: *Op. cit.*, p. 1.

Cambrian gneisses and associated pegmatites. These pre-Cambrian rocks form the northeast-southwest ridges of the Highlands. Intermontane valleys lying 400 to 600 feet below the tops of the ridges are floored with Paleozoic limestones, quartzites and shales.

The foliation of the gneisses parallels the trend of the ridges except in the Oxford area where it strikes northwest. There is considerable evidence indicating that the direction of foliation is here a result of the shapes of pre-existing blocks around which the later intrusives were molded and along the structures of which the later magmas were injected. In places in this area the foliation of the common gneiss is seen to conform to the contact with masses of older gneiss, even when that contact pursues a rather sinuous course.

Throughout the Highlands area large strike faults bound the gneissic ridges. In the Oxford area only a few transverse faults have been detected. One such fault intersects the Washington vein with a horizontal displacement of twelve feet.

DESCRIPTION OF THE ROCKS.

Bayley [3] recognizes three types of gneiss in the Highlands area to which the names of Pochuck, Byram, and Losee gneiss have been given. Pegmatites of varied composition are associated with all the gneisses. All are of pre-Cambrian age, the Pochuck gneiss being the oldest.

Besides the gneisses and pegmatites, the pre-Cambrian complex includes the Franklin formation, a white to gray crystalline limestone which has a limited distribution, mostly in the valleys of the Highlands. A large area of this limestone occurs one mile north of Oxford, and within it were two magnetite deposits of considerable size. However, since this paper is concerned only with ores in gneiss, this limestone formation need not be described further.

The Pochuck Gneiss.—The Pochuck gneiss is a distinctly foliated, dark-colored rock, composed largely of hornblende, biotite, augite, plagioclase, orthoclase, and quartz, with minor amounts

[3] Bayley, W. S.: *Op. cit.*, pp. 120–124.

of magnetite and apatite. Near the contacts with pegmatites or ore bodies, the rock may contain considerable amounts of garnet and scapolite.[4] This gneiss varies widely in composition. Any one of the dark silicates may predominate to the exclusion of the others, and in places microcline and microperthite are more abundant than plagioclase. The plagioclase is mostly oligoclase, but near Oxford it is in part labradorite. All these minerals are unaltered except in close proximity to ore or pegmatite.

A large area of Pochuck gneiss occurs two miles north of Oxford. Several other areas too small to map were found elsewhere in the Oxford region. These smaller areas occur as blocks engulfed in the later intrusive gneiss. Undoubtedly such occurrences are widespread throughout the whole Highlands region but their presence in most cases is obscured by the deep cover of residual soil and glacial drift.

Large masses of Pochuck gneiss are encountered in the Washington mine where it forms part of both the footwall and hanging wall of the ore body. Much of this rock is intimately mixed with later gneisses and pegmatites which have been intruded and injected into it. This modified phase of the rock will be described later.

The Pochuck gneiss has been regarded as partly sedimentary and partly igneous in origin.[5]

The Byram Gneiss.—The typical Byram gneiss commonly occurs in narrow strips or lenticular areas in the New Jersey Highlands. This is a potash-rich rock consisting of quartz, microperthite, microcline, orthoclase, hornblende, apatite, titanite, magnetite, and in places, pyroxene and biotite. There is much variation from the typical rock. The color is dark or light gray, according to the percentages of dark silicates present.

The Byram gneiss exhibits a distinct foliation and in places a well banded structure, both of which are regarded as primary in origin. Slight crushing or distortion of the minerals is discernible.

[4] Identified by Dr. A. A. Pegau, University of Virginia.

[5] Bayley, W. S., Kummel, H. B., and Salisbury, R. D.: U. S. Geol. Surv. Folio 191. Raritan Folio.

The Losee Gneiss.—This is a soda-rich rock consisting principally of oligoclase and quartz, with lesser amounts of pyroxene, hornblende, biotite, apatite, magnetite, titanite, and zircon. Microcline, microperthite, and orthoclase are less common. In certain phases, however, these minerals occur in greater proportions, and the Losee exhibits all gradations into the Byram gneiss.

The typical Losee gneiss is light gray to nearly white in color. It shows a less distinct banding than the Byram gneiss, and may be quite granitic. The quartz grains may be elongated or form lens-shaped aggregates, and the dark minerals occur in discontinuous bands parallel to the foliation.

The Byram and Losee gneisses are intrusive into and distinctly younger than the Pochuck gneiss. But they appear to be essentially contemporaneous with each other and are probably differentiates of the same original magma. In some belts one type of gneiss occurs to the exclusion of the others but in most cases masses of each occur. These grade into each other through intermediate phases.

In the Oxford area the rock is intermediate between typical Byram and typical Losee gneisses. It consists of oligoclase, perthite, and microcline; quartz may equal the most abundant feldspar; orthoclase is in minor quantity or absent; hornblende, augite, and biotite are subordinate to the feldspars, and in places one or even two of these minerals may be missing; accessory minerals such as muscovite, zircon, apatite, titanite, magnetite, pyrite, and molybdenite may also occur.

This rock exhibits the structural variations that are found in the typical Byram and Losee gneisses. Adjacent to inclosed bodies of ore and pegmatite, the quartz and feldspars commonly show greater pressure effects, and hydrothermal alteration has resulted in the development of chlorite, epidote, pyrite, sericite and calcite.

The Pegmatites.—Intrusive into all the gneisses are pegmatites that contain practically the same minerals as the gneisses, but in different proportions. Plagioclase, orthoclase, microcline or microperthite may form the dominant feldspar. Each of these

minerals may be entirely absent or may be present in any proportion. Quartz is present in variable amounts. Hornblende, augite, and less commonly biotite are components of most pegmatites, and any one of these minerals in combination with quartz may make up the whole rock.

Apatite, zircon, titanite, pyrite and magnetite are common accessory minerals, and a little garnet and tourmaline may be present. By increase in amount of magnetite, the pegmatite grades into ore. Chlorite, epidote, sericite, and calcite occur as introduced minerals resulting from alteration by hydrothermal solutions.

The great variation in mineral composition of the pegmatites becomes simpler when their relationships are determined. There is a primary granitic pegmatite containing practically the same minerals as the country gneiss of which it is a differentiate. From this primary phase there is a gradation toward a later formed pegmatite composed of hornblende with or without other mafic minerals. Or the gradation may be toward a phase composed entirely of feldspars and quartz. This latter phase in turn grades into quartz veins. Any of the intermediate phases or either of the extreme end phases, except the quartz veins, may grade into ore, this transition commonly being abrupt.

The texture varies from fine-grained in some of the primary granitic pegmatites to coarse in the later phases, in which feldspar and hornblende crystals may exceed an inch in length. The pegmatite may occur as irregular masses or nests included in gneiss, with the one grading into the other. Where intrusive into the older Pochuck gneiss, the contact is likely to be sharp. More commonly the pegmatite forms lens-like bodies conformable with the foliation of the enclosing rock. In a few cases it occurs as dike-like masses that cut across the structure of the gneisses. Where the gneiss has been intruded by large quantities of pegmatite the banding is complexly crumpled.

Modified Injection Gneiss in the Washington Mine.—In the Washington mine there is a border phase of great variation occurring between the Pochuck and later gneisses. This contact

zone is well exposed in the lower levels of the mine, where crosscuts from the shaft to the ore body have intersected it for a distance of over 200 feet. Large blocks of the older gneiss are in places entirely engulfed by the later gneiss. In places the contacts are sharp, or the xenoliths have frayed edges, or there is a feathering-out of the xenoliths with gradual transition into the later gneiss. Many of the included blocks are from six to eight feet long and one or two feet wide, but the majority are much smaller. Probably the Pochuck gneiss, which forms the hanging wall in most places, is part of an enormous engulfed block.

In most places the schistosity of the included block conforms to that of the later gneiss, in other instances the blocks are oriented obliquely to the structure of the enclosing rock.

The later pegmatitic magmas were also injected into the Pochuck gneiss on a large scale. These magmas, being thinner, have penetrated along the foliation resulting in a *lit-par-lit* structure. The pegmatite may occur as augen or veins between the layers of dark gneiss. The latter type of occurrence gives a rock with a marked banding. There are all gradations between small augen and large lenses of pegmatite, some ten to a hundred feet in length. Much of the older gneiss was entirely digested by the pegmatite magmas, resulting in hybrid types of rock.

Where large volumes of pegmatite were injected along the foliation of the Pochuck gneiss, complex flexures and contortions of the bands have commonly resulted. This crumpling is of a minor order. A zone only a few feet wide may be highly contorted, whereas adjacent to it the bands may be simply forced apart without any such distortion. Fenner[6] has given a more detailed description of similar injections into Pochuck gneisses in another locality in the Highlands.

THE WASHINGTON VEIN.

Form, Size, and Shape.—The Washington vein at Oxford and the other veins just to the northeast and parallel to it are typical

[6] Fenner, C. N.: Mode of Formation of Certain Gneisses in the Highlands of New Jersey. Jour. Geol., vol. 22, pp. 594–612, 694–702, 1912.

of the larger magnetite ore bodies of the New Jersey Highlands as described by Bayley [7] and Nason.[8] It is pod- to lens-shaped and conforms to the foliation of the inclosing gneiss (Figs. 1 and 2).

This vein has a length of over 1800 feet, a maximum depth of

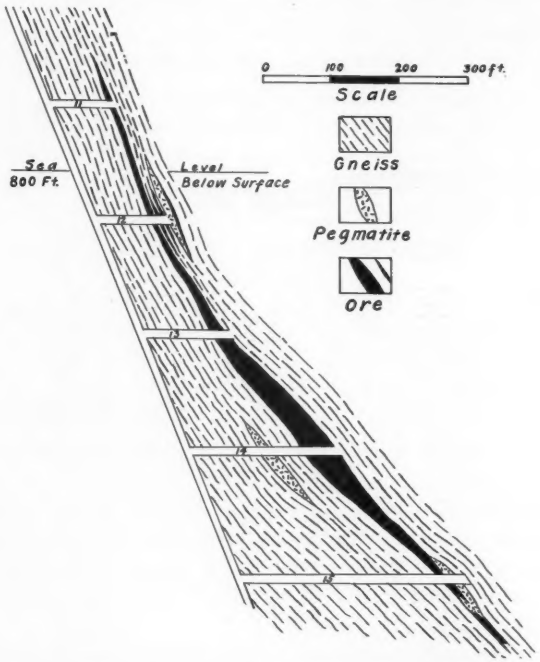

FIG. 1. Cross section of southeast end, Washington vein.

over 1000 feet, and a thickness throughout most of its extent of about 30 feet. The strike varies from N. 25° W. at the southeast end to N. 55° W. at the northwest end. The dip is from 45° to 75° northeast and the pitch 30° to the southeast.

[7] Bayley, W. S.: *Op. cit.*, pp. 135–140.

[8] Nason, F. L.: The Geological Structure of the Ringwood Iron Mines, New Jersey. Tr. Amer. Inst. Min. Eng., vol. 24, pp. 505–520, 1894.

Many of the ore veins described by Bayley and Nason show alternate pinching and swelling, along both the strike and dip, so that the ore bodies occur in series, like flat beans in a pod.

In the east end of the 14 level the ore body splits into two tapering veins. Elsewhere there is a gradual pinching out at the ends in the direction of strike. Stringers of ore and pyrite or of vein quartz in places extend fifty feet or more beyond the ore body proper. Similar narrow tapering veins also occur in the

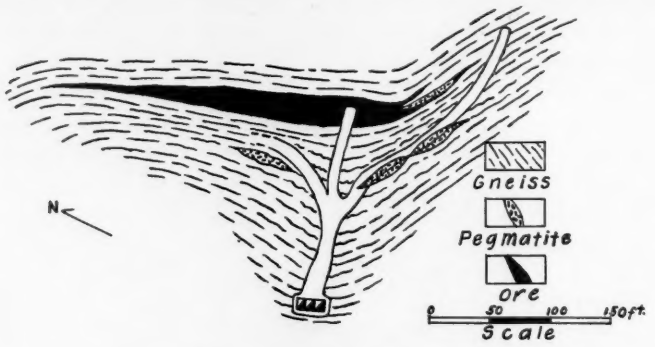

FIG. 2. Plan section, Washington vein, 14 level.

wall rock parallel to the main vein. There are all transitions from such occasional thin veins to rock that consists of alternating magnetite and gneiss bands, giving a sort of book structure. In such cases the individual bands vary from a fraction to several inches in thickness.

Character and Composition of the Ore.—The ore is a hard homogeneous aggregate of magnetite grains from 1 to 5 mm. in diameter. Most of the grains have one or more crystal faces. Pyrite is invariably present, and in places there is a little pyrrhotite. Ore from early workings contained as much as 4 per cent. sulphur, but this has decreased greatly with depth. Old analyses of ore from the Washington vein give about 0.10 per cent. titanium and 0.50 per cent. phosphorus.

The gangue minerals are practically the same as those compos-

ing the granitic gneiss and pegmatite. They consist of hornblende, pyroxene, mica, quartz, feldspar, apatite, and titanite, with smaller amounts of zircon, chlorite, epidote, sericite and calcite. Garnet and molybdenite occur in the wall rocks and pegmatite. Bayley,[9] however, reports the presence of both of these minerals together with fluorite in some ore bodies.

The ore is intersected by two or more systems of joints that may be so closely spaced as to make it blocky. The magnetite crystals are also intersected by microscopic fractures. These joints and fractures are filled with the propylitic minerals, calcite, and in places, thin seams of quartz.

Masses of pegmatite occur throughout the ore and between it and the enclosing gneiss. Small lenses and irregular nests of quartz, probably always of later crystallization, also occur in the magnetite.

Paragenesis of Ore and Gangue Minerals.—The augite, hornblende, biotite, feldspar, quartz and apatite in the ore are older than magnetite. The magnetite surrounds and replaces all these minerals. In places much of the augite was altered to hornblende before being replaced by magnetite. This alteration differs from uralitization which was produced by late end-phase solutions. The change to hornblende took place along a solid front rather than proceeding along the cleavage or developing a ragged border with shreds of hornblende through the augite.

Pyrite veinlets cut across the magnetite. Much of the titanite also was definitely determined to be later than magnetite, but some of it may be earlier.

Sericite, chlorite, epidote, and calcite are always later than the magnetite, and fill microscopic fractures across magnetite crystals. Biotite occurs in some fractures along with the above minerals, and therefore is partly later than the magnetite. Quartz is both of early and late generation. It occupies thin seams that cut the ore, and may occur in lens-like masses also of late origin. It was deposited throughout the whole period of crystallization beginning with the formation of pegmatites and ending with

[9] Bayley, W. S.: *Op. cit.*, pp. 151, 152.

veins of pure quartz. Besides the fillings in fractures, chlorite and calcite occur as aureoles around magnetite and between it and the early-formed silicate minerals. These aureoles are not reaction rims, but are later depositions along mineral contacts. This is shown by their continuity with veinlets in the magnetite. Some sericite and biotite also have the same occurrence.

The Ore-Gneiss Contact.—The ore lies mostly in contact with Pochuck gneiss and its injected phases. But, in part, it is enclosed by the later gneiss and its pegmatitic phases, which have intimately intruded and engulfed the older gneiss.

Where the ore is bounded by gneiss the contact is sharply defined (Fig. 3). Irregular and gradational contacts occur only

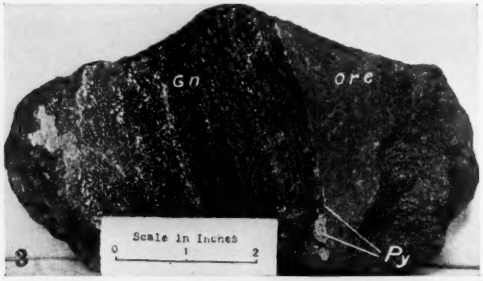

FIG. 3. Showing sharp contact between ore and gneiss.

where the ore is in contact with pegmatite. In many places magnetite and pyrite have impregnated the wall rocks and are disseminated through it for several feet beyond the contact. The joints in the enclosing wall rocks contain no magnetite but are commonly filled with thin seams of chlorite, calcite and quartz. Magnetite does occur, however, as a partial filling of certain microscopic fractures which are abundant in the wall rock within an inch or two of the ore, especially if that rock is coarse-textured.

Apophyses of magnetite, except on a microscopic scale, do not extend into the wall rock. Neither do the walls show any chilling effects.

GENESIS OF THE ORE DEPOSIT.

Origin and Character of Ore Solutions.—Bayley [10] says,

> In all cases the ores are regarded as being of magmatic origin . . . after the partial cooling of the gneisses these were in turn intruded by ferruginous portions of the same magma that gave them birth, and these intrusions were later enriched by iron-bearing solutions or vapors originating in the same subterranean source. . . . In their transit to the surface these solutions or vapors deposited additional magnetite in the intruded ferruginous rocks and made the ore lenses.

Bayley, thus, has the concept of successive differentiates, from a common magmatic reservoir; an early differentiate depositing the pegmatites rich in hornblende, pyroxene, and biotite, and a later one depositing the ore.

Bayley [11] believes the magnetite associated with the pegmatites to be of two generations, "The first of which crystallized before any of the other constituents of the rock, and the second after all the others had been formed." He further believes that the vapors or solutions in which the magnetite was transported, may have deposited ore by replacement of the rock through which they circulated. "In some places there may have been replacement of the silicates by magnetite, causing further enrichment of the mass."

The writer agrees in the main with Bayley's views so far as they apply to the lens-shaped ore deposits. However, the writer believes that practically all the magnetite was deposited later than the primary silicate minerals.

That the ore solutions may be differentiates of the same solutions from which the pegmatites were deposited, is indicated by the intimate association of the ore and pegmatite. At Oxford and elsewhere the ore grades into the different phases of pegmatite which may be associated with it.

The first differentiate from the parent magma deposited a pegmatite very similar in mineral composition to the granitic gneiss. This primary pegmatitic residuum split into acid and

[10] *Idem*, p. 149.
[11] *Idem*, p. 151.

basic phases; the one gave a pegmatite solution high in quartz and feldspar constituents from which in turn magnetite was later separated, and the other gave a pegmatite solution high in hornblende, pyroxene and biotite constituents from which magnetite also was later deposited. Gradations between these two varieties of pegmatite occur, but, apparently in every case, the magnetite was deposited after the crystallization of the primary silicate minerals.

The siliceous solutions from the early granitic pegmatite magma underwent a further splitting, giving solutions from which the quartz veins were deposited. This vein quartz is later than any of the magnetite.

Most of the magnetite, however, was carried to its present position by solutions that, originating in some common deep reservoir, followed the injection of the earlier granitic pegmatitic solutions. These later ore magmas for the most part carried little else than magnetite. Most of them apparently underwent little further differentiation after once in transit. But, from others containing greater abundance of silicates, pegmatites were first separated and deposited by selective crystallization; these were followed by gangue minerals and ore, and lastly by vein quartz.

Time of Deposition.—That the ore was deposited subsequent to the development of the foliation of the gneisses is indicated by several facts. The ore bodies are concordant with the structure of both the Pochuck and later intrusive gneisses. In the case of the book-ore, the magnetite has in part replaced certain bands in the gneiss. However, the intervening bands give evidence, to be described later, which indicates that pressure was developed during the deposition of the ore. Some pegmatites cut across the gneissic structure. If these pegmatites, like all others where their relations could be determined, are older than the ore, then the ores also were injected after the development of the foliation.

Pyrite, biotite, chlorite, epidote, sericite, and calcite occur in thin seams in the ore and in the gneissic and pegmatitic wall rocks. These minerals are believed to have been deposited from solutions

shortly following the ore magmas. But the absence of magnetite in similar fractures suggests that the fracturing occurred subsequent to the injection of ore but prior to the last-phase solutions related to this ore injection.

Deposition by Displacement and Replacement.—Bayley makes no specific statement that the deposition of the ore was accompanied by displacement of the wall rocks. But we assume that he uses the term " intrudes " with the underlying idea that ore magmas forced their way upward and that the method of deposition was mainly by displacement of the adjacent rocks. This inference appears the more certain when he later states (see previous quotation) that in some places there may have been replacement of the silicates by magnetite, causing further enrichment of the mass.

Colony,[12] in his bulletin on the magnetite ores of southeastern New York, described several ore bodies which are apparently similar to the prevalent type in New Jersey. He ascribes deposition to replacement along directions controlled by the rock structure.

The writer believes that most of the deposits of New Jersey (with exceptions later described) have been emplaced both by replacement and displacement. But in most instances replacement of the host rock was the subordinate process. The intimate association and analogous distribution of pegmatite and ore indicate a similarity of origin. Numerous pegmatite bodies have a lenticular shape. The gneissic banding bends around the pegmatite, perfectly conformable with the contact.

Several of the ore bodies described by Bayley occur in a series of lenses with the structure of the enclosing rock conforming to the contact. Similar occurrences of pegmatite were found in the Oxford mine. They have often been described and are generally accepted as due to deposition under pressure. Where the pegmatitic solutions were forced along the bands, complex crinkling and buckling of the gneissic structure resulted. The pegmatites, like the ore bodies, commonly split and fork, but this too is a feature resulting from pressure. If the pegmatites came to their

[12] Colony, R. J.: The Magnetite Iron Deposits of Southeastern New York. N. Y. State Mus. Bull. Nos. 249–50, p. 70, 1921.

present positions by spreading the rock walls apart, the magnetites, so closely associated with them and so similar in form, must have been similarly emplaced.

In blocks of granitic gneiss taken from the D. L. and W. railroad tunnel, one-half mile east of the Washington mine, numerous sections of a high grade ore vein are exposed. This vein, with a maximum thickness of six inches, gradually pinches to a mere stringer following the foliation of the gneiss. The contact between ore and gneiss is sharply defined, the transition being made by a thin zone of silicate minerals with interstitial magnetite. This transition zone is only from one-eighth to one-fourth inch in thickness. With the exception of this minor irregularity the vein wall is conformable to the schistosity of the gneiss. Thin sections from this contact show that the magnetite has replaced silicate minerals. The replacement proceeded along mineral boundaries and not by selection of certain minerals. But the volume of ore deposited by replacement is believed to be subordinate to the amount of space gained by displacement of the wall rock. Considerable crushing of the rock minerals and bending of the plagioclase lamellæ have occurred (Figs. 4–6).[13] An inch or more away from the ore vein no such pressure effects are in evidence.

The fact that fractures are numerous only within a fraction of an inch from the ore-gneiss contact suggests that their origin is related to that of the ore vein. That they did not exist prior to the injection of the magnetite is evidenced by the fact that, though the fractures are filled with biotite, chlorite and other late-stage minerals, they are penetrated only in places by a few microscopic grains and stringers of magnetite. If they had existed before the injection of the ore solutions, magnetite would have penetrated them in preference to the mineral sutures. Also they were not formed after the deposition of the ore, for the magnetite crystals and the chlorite veinlets and aureoles are intersected by but few of the numerous fractures in the adjoining gneiss. The conclusion is that the crushing was developed after the beginning of

[13] The photographs for this paper were kindly made by Dr. J. K. Roberts, University of Virginia.

FIG. 4. Photomicrograph showing bent augite crystal (*A*) and veinlet of magnetite (*Mt*). Biotite, *Bi;* orthoclase, *O*. Ordinary light, × 25.

FIG. 5. Photomicrograph showing bent plagioclase lamellæ at contact with magnetite vein (*Mt*). Crossed nicols, × 25.

FIG. 6. Photomicrograph showing crushing of silicate minerals near contact with magnetite vein (*Mt*). The gray minerals are mostly plagioclase, with some microperthite, apatite and zircon. Fractures are filled with biotite, chlorite, calcite, and sericite. Ordinary light, × 9.

ore deposition but before the cessation of the hydrothermal action that closely followed it.

The book structure suggests replacement, but thin sections revealed lamellæ of biotite and plagioclase bent in such a manner as

to indicate the exertion of pressure by the growing magnetite crystals.

Further evidence of emplacement without large-scale replacement is indicated by the lack of embayments of magnetite in the gneiss. With the exception of the forking veins, the ore contact is conformable to the gneissic structure, and is also sharply defined. This sharpness is sometimes maintained on a microscopic scale, even when different minerals lie against the ore (Fig. 3). There is therefore a lack of preferential replacement such as would be expected if replacement had occurred. Where the ore is in contact with pegmatite, irregular and indefinite boundaries usually do occur; but this is to be expected when the origin of the two is considered. The pegmatite crystallized from the magma first and magnetite later, with all transitions gradual and abrupt between the final products.

The ore body shows no evidence of any structure that may have been inherited from large-scale replacement of a well-foliated gneiss. The horses of rock in the ore body are mostly pegmatite. In places, gneiss occurs within ore but this results from the forking of the ore vein.

Many of the ore bodies that were worked long ago were mere pockets in gneiss. They are small, irregular in shape, and in places contain considerable gneissic rock as gangue. Such ores were apparently deposited by replacement alone. But the large, tabular, lens- and pod-shaped bodies have been emplaced largely by displacement of the rock walls, with only minor replacement.

Hydrothermal Alteration.—The enclosing rocks exhibit the effects of end-phase hydrothermal alteration in the vicinity of the ore body. This is particularly true of the pegmatite which, probably due to its coarser texture, is commonly more fractured than the gneiss.

The secondary minerals are scapolite, biotite, sericite, chlorite, epidote, calcite, and quartz. All of these except scapolite occur in fractures and as alteration products of the primary silicates. Some of the scapolite contains vermicular intergrowths of quartz.

Most of it has been altered by later solutions to sericite and epidote.

In places large amounts of garnet occur in the gneiss, especially near the pegmatites. This mineral was probably all formed during the early pegmatitic stage and prior to the deposition of magnetite.

Undoubtedly considerable secondary quartz has been introduced into the wall rocks but, because of the difficulty of distinguishing it from primary quartz, the extent to which such introduction took place could not be determined.

The Loci of the Ore Bodies.—As elsewhere described in this paper, Pochuck gneiss, and modified phases of it, form a large part of the wall rock of the Washington vein. The writer has examined the dump piles of a number of the old mines in the Highlands area. In every case, where the ore body is known to have been of large size and lens-shaped, Pochuck gneiss and phases of it were found closely associated with the ore. It is believed that the contact zone between the Pochuck and later intrusive gneiss constituted a large-scale structural weakness which in most cases determined the locus of ore deposition.

It is not to be understood that the ore bodies are located along any sharply defined boundary between the two types of rock. The rock lying between the several nearly parallel ore bodies at Oxford apparently consists of large blocks of Pochuck gneiss engulfed in a larger area of later gneiss. These blocks are greatly modified by injections of the later gneiss and pegmatite. Thus the contact zone between the two gneisses is not a sharp one. But the common occurrence of the ore bodies associated with these contact-zone rocks suggests structural control.

DISSEMINATED ORES IN GNEISS.

A few ore deposits of the Highlands consist simply of magnetite-rich gneiss with all gradations between ore and country rock. Such an ore body is found at the Scrub Oaks mine near Dover, New Jersey, now operated by the Allan Wood Mining Co.

The nearby Erb and Baker No. 1 ore bodies are of the same type.

In this area the country rock is a medium, even-granular, gray, granitic gneiss showing only slight foliation. It consists largely of quartz with about equal amounts of orthoclase and plagioclase. The plagioclase is mostly albite. Microcline, microperthite, muscovite, and biotite occur in subordinate quantities. Accessory minerals are chlorite, zircon, titanite, and magnetite. The chlorite occurs along minute fractures as introduced material. Magnetite is uniformly distributed in the normal country rock, some of it in euhedral crystals.

Small masses of pegmatitic material occur through the gneiss, in places as irregular bunches but more commonly showing more or less parallelism to the schistosity. Large lenses or masses of coarse pegmatite are lacking.

As the ore body is approached the magnetite increases. Much of it occurs as films and stringers parallel to the gneissic structure, and the remainder as a filling around the silicate minerals. In places where magnetite has been abundantly deposited parallel to the schistosity, the resultant rock has a marked banded appearance. The gradation from normal granitic gneiss to ore commonly takes place within a zone ten to twenty feet in width. Ore and country rock contain the same minerals but in different proportions. Besides magnetite, the ores contain greater amounts of pyrite, chlorite, and sericite. The disseminated ores in contrast with the pegmatitic ores contain little phosphorus.[14]

Workable ore carries a little over 40 per cent. iron. It has been opened for a length of 3500 feet and a width of 35 feet, the walls of the ore body of course being quite indefinite.

Nothing that could be identified as Pochuck gneiss or any of its phases was found in the country rock. It is presumed that as differentiation in depth occurred, there was no nearby pronounced structural weakness along which ascending magmas could readily penetrate. They were therefore forced upward by diffusion through the already consolidated parent rock, their courses being largely guided by the schistosity of the rock. The magnetite is

[14] Personal communication by Mr. R. E. Crockett, Supt., Scrub Oak Mines.

unmistakably later in origin and was deposited by replacement. This can be seen readily in hand specimens. The magnetite surrounds corroded remnants of the silicate minerals.

The disseminated ores were probably deposited by replacement alone. At least there is no evidence by which attendant displacement of the adjacent rocks can be proved. But why these disseminated ores were deposited by replacement, whereas the lens-shaped bodies are largely due to displacement of the wall rocks, the writer is unable to explain.

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SILVER AND BISMUTH-BEARING GALENA FROM LEADVILLE.[1]

E. P. CHAPMAN AND R. E. STEVENS.

IN A study of the ores of the Greenback ore body in the Leadville mining district, Colorado, during 1930 and 1931, several minerals were found which, as far as the writers are aware, have never been reported from the Leadville district. Some of these minerals proved difficult of identification, and, at the suggestion of Dr. Loughlin, of the U. S. Geological Survey, a suite of specimens was submitted to Dr. M. N. Short for review. Dr. Short found one mineral, concerning which he says:

> The physical properties and etch tests check closely with those of galena, but the microchemical tests clearly show bismuth and silver. I am inclined to believe that this is a bismuth and silver-bearing galena rather than an argentiferous lead-bismuth sulphide. There are a large number of lead-bismuth sulphides known but none of them is isotropic. The specimen contains as inclusions perhaps 5 per cent. pyrite and less than 1 per cent. each of sphalerite and chalcopyrite. A chemical analysis should be made.

The analysis was made by the second author, and is described in this paper. After it was completed there was still doubt as to whether the mineral was a new species in the crystallographic sense, although its composition, appearance, and structure were new. At this point Dr. Paul F. Kerr, of Columbia University, kindly offered to coöperate by making x-ray diffraction patterns of the mineral. These agreed so closely with those of ordinary galena that there could be little doubt that the mineral was largely galena (Fig. 1). As a solid solution, and in its properties, the mineral is new, but owing to the high proportion of lead sulphide and for other reasons, the writers feel that it would be unwise to propose a special name for this mineral. It is a variety of galena.

[1] Published by permission of the Director of the U. S. Geological Survey.

THE ORE BODY (E. P. C.).

The Greenback[2] ore body occurs in the Graham Park Basin, about one mile east of Leadville, Colorado, in the California Mining District. In some respects it resembles a chimney deposit, although lacking the brecciated character of such, and is roughly elliptical in outline with a border of zinc-lead sulphides and a core of low grade pyrite. The north and east borders are nearly vertical; the south is partly vertical and partly follows the

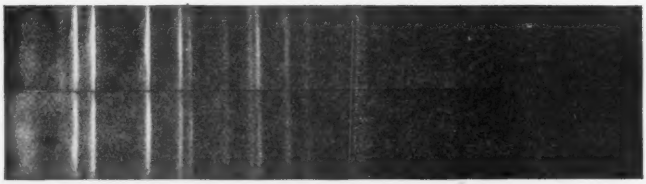

FIG. 1. X-ray patterns of the new mineral (above) and of ordinary galena (below), showing the similarity of crystal structure.

Tucson-Maid reverse fault. The west border is irregular and the ore minerals extend upward along favorable beds in the "white" (Manitou) limestone for considerable distances. The deposit shows a casing of manganosiderite which gradually changes to unaltered limestone about 50 feet from the ore body. The ore body is connected downward to several veins which appear to follow the nearly vertical Cambrian quartzite transition beds along the Tucson-Maid fault. The entire thickness of "white" limestone has been replaced in the ore zone. Above the limestone, the Parting quartzite has been attacked to some extent by the mineralizing solutions, but not sufficiently to form deposits of commercial value. Many well formed crystals of pyrite, galena, and sphalerite occur in this horizon, however. Above the Parting quartzite and below a sheet of "gray" porphyry, a thickness of about 50 feet of "blue" limestone has

[2] Emmons, S. F., Irving, J. D., and Loughlin, G. F.: Geology and Ore Deposits of the Leadville Mining District, Colorado. U. S. Geol. Survey Prof. Paper 148, pp. 275–276, 1927.

been replaced by an ore body that follows the lower edge of the porphyry sheet upward at a low angle to the northwest. The "blue" limestone above the porphyry sheet, which is here about 50 feet thick, contains no ores immediately over the ore bodies in the lower formations, but has been the location of important ore bodies further northwest.

Cutting through the pyrite core is a zone containing higher silver than the rest of the deposit. This zone is from 10 to 20 feet wide and extends in a northwest direction and has a nearly vertical dip. It is not marked by any shearing or vein structure, but its southeast end is in line with a branch of the Tucson-Maid fault that has a small reverse throw. This fault, which is only visible outside the ore deposit, may have exercised a controlling influence on the location of the silver zone that extends entirely through the "white" limestone horizon, the upper parts of which were found and mined by former operators. The suite of specimens in which the new minerals were found came from the lower part of this zone from 1300 to 1400 feet below the surface.

Associated Minerals and Paragenesis (*E. P. C.*).—The principal mineral is pyrite. Around the borders, sphalerite and galena are more prominent but in the core they are scarce. These three minerals formed the first epoch of the deposition of ore minerals, probably replacing manganosiderite.[3] As determined by the study of polished surfaces under the microscope, pyrite preceded the other minerals in deposition and sphalerite was in general earlier than galena, although reversals in the order of these two minerals have been noted. In the mine, the diffusion banding described by Loughlin[4] is often plainly evident, especially in the mixed sulphide ore around the borders of the deposit, but these bands are too wide to show up well in specimens of suitable size for microscopic study.

The sphalerite is the iron-bearing variety, marmatite, and in the lower part of the deposit, contains many small inclusions of chalcopyrite. Some of these are round and large enough to be

[3] *Idem*, Chap. 9.

[4] *Idem*, pp. 202–205.

seen on the polished surface with the unaided eye. Others are lath-shaped and evidently have formed along cleavage lines in the sphalerite (emulsion structure). In the upper part of the ore body the round inclusions seem to be lacking and the elongate forms are much smaller, so that a magnification of 300 is necessary to see them; in some places, especially where the ore deposition has followed the contact a long way from the main body, they seem to be missing altogether. Whether an unmixing of a solid solution or a partial replacement, the change in size and shape of the inclusions may possibly indicate the proximity of the deposit to some feeder channel, such as the broken zone along the Tucson-Maid fault.

A distinct later period of mineralization, much less intense than the former, is found in the silver-rich zone mentioned above. The principal mineral of this later period is chalcopyrite; associated with it are a little galena and sphalerite, the new mineral described in this paper, aikinite, altaite (?), galenobismutite, hessite, tetrahedrite, an undetermined, strongly anisotropic galena-white mineral, and perhaps others. These minerals fill cavities and cracks in the earlier deposit, which was somewhat crushed before the later deposition. They occur in minor amounts, but have introduced sufficient silver to bring the ores up to commercial value.

Monthly composite samples of the shipments to the smelter were analysed for copper, arsenic, antimony, and bismuth, and showed considerable variation from month to month. The average results were: Cu—0.5%, As—0.2%, Sb—0.05%, and Bi—0.05%. The large amount of arsenic compared to bismuth suggests that other minerals containing this element may be present. The microscopic work failed to disclose any mineral containing arsenic except the very small amount of tetrahedrite, which gave a positive microchemical test for that element as well as antimony.

Description of the Later Ore Minerals (*E. P. C.*).—Identification of the minerals was based mainly on etch reactions and microchemical tests. The new mineral to be described was the

only unusual one found in suitable quantity for chemical analysis.

The galena of the later mineralization gives a microchemical test for bismuth and in this respect it differs from that of the first period. It has a well developed cubic cleavage and in all other respects is normal, being quite different, however, from the new mineral, both in appearance and intensity of etch reactions. Dana [5] suggests that the octahedral cleavage sometimes seen in galena may be due to a small percentage of bismuth, but this cleavage was not noted in the galena examined.

The identification of altaite is open to some question. The mineral is very white, has poorly developed cubic cleavage and is isotropic. It gives good microchemical tests for lead, tellurium, bismuth, and silver. Short says:

> The color, cleavage and isotropism as well as microchemical tests would indicate that the mineral is altaite, but it differs from the usual altaite in that the HCl etch test is negative and effervescence with HNO_3 doubtful. The presence of bismuth and silver may be due to their inclusion in solid solution in the altaite.

Mixed with the altaite are numerous minute inclusions of a strongly anisotropic mineral which it was impossible to determine microchemically as the particles were too small. These inclusions are lath-shaped and look as if they had been deposited from a solid solution in a host mineral. The determination of the other minerals was definite.

There has been a small amount of supergene sulphide enrichment, indicated by chalcocite and native silver, found bordering cavities in the ore and veining the different sulphides. Some of the carbonates appear to be supergene also. They have a faint pink color and give strong qualitative tests for manganese and magnesium, a weaker test for iron, and contain only a trace of calcium. In one specimen, blebs of native silver, which may be hypogene, were found inclosed by aikinite which in turn was inclosed by chalcopyrite. The gangue minerals are quartz (chert) and carbonate, mostly manganosiderite.

[5] Dana, E. S.: A System of Mineralogy, 6th ed., p. 49, 1911.

THE NEW MINERAL (E. P. C. AND R. E. S.).

This is best described as a silver and bismuth-bearing galena, approximately $Ag_2S.Bi_2S_3.11PbS$ in composition. The mineral is indistinctly crystalline, also massive. Cleavage, cubic, poorly developed. Color, light to steel gray. Luster metallic, inclined to be brilliant. Opaque. Streak, dark gray. Hardness, soft, 2–3. B.B. on charcoal decrepitates violently. With soda, gives metallic button with lead and bismuth coating. Soluble in hot concentrated HCl and HNO_3.

Microscopic. Color, white. Hardness, soft, B–C. Isotropic with poorly developed cubic cleavage. Dark gray powder.

Etch Reactions:

HNO_3–R Turns black, fumes tarnish, may be slow effervescence. The etched surface shows a pattern which varies considerably in different areas; in places a sort of irregular grain structure is developed with the lighter part of the etched surface forming the border; at other places irregular, rounded inclusions of the lighter part of the surface are found in the darker part of the area; at other places small needles of the dark area arranged in a sort of box-work pattern at right angles to each other invade the lighter parts of the area.

HCl–R Slowly turns brown to black, some areas almost unaffected, and some iridescent. The same pattern as seen when etched with HNO_3 shows to a limited extent.

KCN–N

$FeCl_3$–R Tarnishes faintly, almost negative.

KOH–N $HgCl_2$–N

Microchemical tests positive for lead, bismuth, silver, and a weak test for antimony.

The etch pattern in acids suggests that perhaps the mineral is not altogether homogeneous in composition but the x-ray diffraction pattern shows only the simple structure of galena.

For chemical analysis the mineral was separated from adhering fine sericitic material by a heavy solution.

Analyses (By R. E. Stevens).

	Sample 152-B.		Sample 106-C.
	Analysis I.	Analysis II.	Analysis I.
Pb	63.90	64.04	61.69
Ag	5.76	6.04	5.89
Bi	11.80	11.47	11.34
Cu	0.23	0.26	0.28
Zn	0.58	0.56	0.67
Fe	1.21	1.48	2.27
As	....	0.10	0.12
Sb	....	0.23	0.62
S	14.44	14.59	15.79
Se, Te	....	None	None
SiO_2	0.72	0.71	0.24
	98.64	99.48	98.91
Specific gravity 7.16			

The analytical methods used were those of Low and of Hillebrand and Lundell. In Analysis I of 152-B, the lead was first removed as the sulphate and purified by three precipitations, after which the other constituents were determined. In Analysis II of 152-B and the analysis of 106-C, the silver was first removed as the chloride by three precipitations and this was followed by the removal of lead, then bismuth. Both samples contained some chalcopyrite, sphalerite, and pyrite. Sample 106-C contained considerable sericitic clay. Of the analyses given, Analysis II of 152-B is probably the best, and is calculated as follows:

Accessory			Fe	S
.26 Cu as	$CuFeS_2$	=	.23	.26
1.25 Fe	FeS_2	=	1.25	1.44
.56 Zn	ZnS	=	...	.27
			1.48	1.97

Substraction of accessories gives:

New Mineral		Recalculated	Ratios
Pb	64.04	67.84	PbS 11 × .998
Ag	6.04	6.40	Ag_2S 1 × .995
Bi	11.47	12.15	$(Bi, Sb)_2S_3$ 1 × 1.008
Sb	.23	.24	or $Ag_2S \cdot Bi_2S_3 \cdot 11PbS$
S	12.62	13.37	
	94.40	100.00	

It is remarkable that the molecular ratios approach so closely to whole numbers. No mineral of exactly these ratios has been described before, but beegerite, $6PbS.Bi_2S_3$ and polyargyrite, $12Ag_2S.Sb_2S_3$, both isometric, are somewhat comparable.

ACKNOWLEDGMENTS.

The writers are deeply indebted to Dr. Kerr for the x-ray tests, to Dr. Short for reviewing the microchemical tests and etch reactions, and to Dr. R. C. Wells for advice and criticism.

SUMMARY.

The Greenback ore body, east of Leadville, is described, together with several unusual minerals, their associations, and microchemical reactions. One lead mineral was found to have a high proportion of bismuth and silver. It differs from galena somewhat in luster and appearance; in having a poorly developed cleavage; in the patterns formed when etched with nitric and hydrochloric acids; in its very weak etch test with ferric chloride; and in its specific gravity. The analytical results approximate to the formula, $Ag_2S.Bi_2S_3.11PbS$, but its x-ray pattern resembles that of galena. It is probably a solid solution of $Ag_2S.Bi_2S_3$ in galena.

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AND
U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

SPECIAL FEATURES OF FINE GOLD FROM SNAKE RIVER, IDAHO.

THOMAS H. HITE.

INTRODUCTION.

MINUTE particles of "flour" or fine gold are observed in the Snake River gravels of such size as to take approximately 4,400,000 or more flakes to make 1 cent in value. Flakes of this size are sparingly present in the material examined, although particles which run from 50,000 to 500,000 to the cent are abundant. This gold is recovered by flotation. Many peculiarly shaped particles of gold are found in the river deposits.

The writer is grateful to Mr. Frank A. Kennedy for flotation concentrates from the plant near King Hill, Idaho. Acknowledgment is made of the coöperation and helpful suggestions of Professor A. W. Fahrenwald and Mr. Joseph Newton of the School of Mines, University of Idaho; and of the checking of numerous weights and results by Mr. Raynard V. Lundquist, Chemist, Idaho Bureau of Mines and Geology. Appreciation also is expressed for the use of facilities and equipment of the School of Mines, University of Idaho, Moscow, Idaho.

SIZE OF PARTICLES.

The observation of very minute particles of gold in the Snake River gravels led to their examination for the purpose of establishing particle size and determining the character of the very small material. This investigation tends to confirm the writer's [1] previous estimate of the size of the more widely distributed or typical flour gold, that it requires approximately 5,000 colors to equal 1 cent in value. Locally, where streams have added coarser

[1] Hite, Thos. H.: Fine Gold and Platinum of Snake River, Idaho. ECON. GEOL., vol. 28, pp. 256–265, 1933.

gold, this number necessarily will be decreased. Indications are that only a small proportion of the large flakes attain sizes over 1 mm. in maximum diameter. However, where local enrichment is present and at the heads of some bars, larger flakes are found. A particular example occurs on the lower Snake River at Clarkston, Washington, where scattered flakes are found between 2 and 3 mm. in maximum diameter. These flakes are very thin, requiring from 5 to 10 of them to be worth 1 cent.

For the purpose of computation 100 disc-shaped flakes were selected which averaged approximately 0.1 sq. mm. in area. Fifteen of these flakes are shown in Fig. 2. Where particles were slightly undersize, larger ones were selected to compensate. The hundred flakes weighed 0.18 mg., making one average sized grain weigh 0.0018 mg. Much of the typical flour gold of the Snake River region is worth at least $19.50 an oz. or 943 fine. On this basis approximately 8800 (8847) such particles are required to weigh one cent in value or about 17,300,000 flakes to one ounce Troy. The weight of a cube of gold measuring 0.1 mm. on a side is 0.0193 mg. Placing the weight of one color at 0.0018 mg., it takes 10.7 flakes to equal the cube in weight. Actually, instead of a cube of gold 0.1 mm. on a side, it would be more convenient to think of the unit as an equivalent cylinder about 0.11 mm. in diameter and 0.1 mm. long. If these colors are regarded as slices of this hypothetical cylinder, their average thickness would be 0.0093 mm. These figures indicate that the thickness of the typical discs of medium size is equal to about one-eleventh of the side of the square area the flake would cover, and an average ratio might be conservatively placed at 1:10. As the particle size becomes smaller, observations indicate that a relatively larger number of the flakes are thicker in proportion to their width; similarly the tendency is for a slight increase in thickness with lessening of size.

Some of the smallest grains obtained from flotation concentrates are shown in Fig. 3. They vary from typical thin flakes to odd nugget-like grains. Examination of a number of these particles and comparative measurements indicate that the thinnest

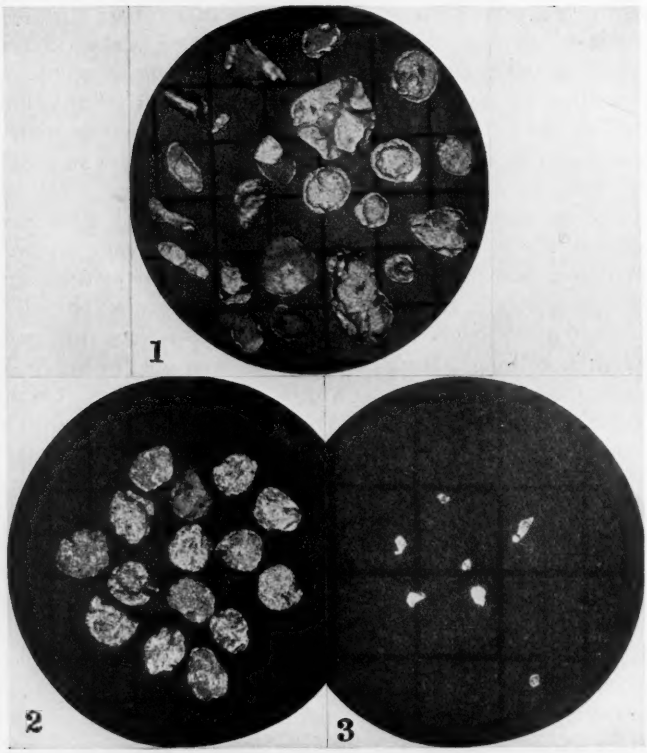

FIG. 1. Odd shaped particles of Snake River gold showing heavy rimmed discs, flakes with bent over edges, rolled particles, and a number of flakes coated mainly with a soft, light gray material probably composed of clay minerals. ×44. Size of grid opening 0.2 mm.

FIG. 2. Fifteen random flakes of flour gold from 100 selected flakes, each approximately 0.1 sq. mm. in area, having a total weight of 0.18 mg. From plant at King Hill, Idaho. ×65. Size of grid opening 0.1 mm.

FIG. 3. Material from flotation concentrates showing minute flakes and grains of Snake River gold. Smallest flake (*a*) attached to long particle at lower tip end. ×130. Size of grid opening 0.1 mm.
and grains of Snake River gold. Smallest flake (*a*) (upper right) attached to long particle at lower tip end. ×130. Size of grid opening 0.1 mm.

flakes tend to approach a maximum ratio of thickness to diameter of 1:10. Due to the irregularities of the material and errors in estimation, combined with the tendency of the smaller flakes to become proportionately thicker, a conservative ratio of 1:5 may safely be used for much of the finest material.

Figure 3 (*a*) shows one of the smallest particles found. It became attached to the upper end of the long flake during mounting. At least 100 flakes of this size are required to cover an area of 0.1 sq. mm., and the thickness may be assumed to be a little less than one-fifth of the side of the square area covered, for the particle is not over one-fifth as thick, *e.g.,* 1.9 microns, as the standard size discs which run 8800 to the cent. About 4,400,000 of these flakes would be required to make 1 cent in value. It is to be expected that similar particles are so thin that they will approach a minimum thickness of one-tenth the standard size flakes, in which case it would require from 7,000,000 to 8,500,000 colors to be worth 1 cent. Doubtless even smaller particles are locally present in the gravel of the Snake River.

It takes 80 particles the size of the flake in the center of Fig. 3 to cover 0.1 sq. mm. Assuming these particles to be about one-fifth the thickness of the standard flakes, it would require about 3,500,000 colors to be worth 1 cent and particles averaging one-fourth the thickness would run about 2,800,000 to the cent.

These figures appear to check closely with the findings of Graton[2] in his examination of the gold deposits in the conglomerates of the Rand. His estimate, based on microscopic studies of the ore and the determination of a mean diameter to be taken for all grains, is that the particles represent a value of from 500,000 to 4,000,000 to the cent. Graton[3] regards the Rand deposits as of hydrothermal origin, but if the deposits should be placer, a large amount of the flaky type of grains ought to be present. It might be difficult in this event to obtain proper orientation in polished surfaces or thin sections to figure satisfactorily

[2] Graton, L. C.: Hydrothermal Origin of the Rand Gold Deposits; Part 1, Testimony of the Conglomerates. ECON. GEOL., Supplement to No. 3, Vol. 25, pp. 124–127, 1930.

[3] *Op. cit.*, pp. 182–185.

the mean diameter of the particles. Graton accepts as conservative the figures of Graham and Wartenweiler,[4] who find about 50 per cent of the gold will pass through a screen having a width of opening of 0.05 mm. and estimate it takes about 40,000 grains to make 1 cent in value. Many writers, however, contend that the gold of the Rand conglomerate is of placer origin. The widespread nature of the Snake River type of deposit points to the possibility of the occurrence elsewhere of deposits somewhat related to or similar to those of the Rand.

SHAPES OF PARTICLES.

Flour gold of the Snake River is composed largely of flattened flakes that have a tendency to be oval or disc-shaped. However, the particles are found to have a wide variety of shapes. Among the very small grains, odd shapes are found and probably there is not such a large proportion of the characteristically thin discs. (Fig. 3.)

Unusual-Shaped Particles.—A wide variety of shapes characteristic of the fine gold occur and some of these are shown in Fig. 1. The more irregular shapes tend to be chunkier grains. Edges may be bent over and flakes may be folded or even rolled. Folding and battering of the edges usually makes the flakes more regular in outline.

Coated grains have been noted in all samples examined, and in many instances the coating has a distinct bearing on the development of flakes of unusual shape. Examination of numerous specimens shows coatings of calcium carbonate and clay minerals. Flakes coated with clay seem to be more generally distributed.

One of the most striking shapes, peculiar to this type of gold, is the disc having a thickened rim. The rim may show on one or both sides of the flake. Several clay-coated particles with partly developed rims are shown in Fig. 1. The coating seems to be the controlling factor in building up the rim, for when the coating

[4] Graham, K. L., and Wartenweiler, F.: A Research to Determine the Size of Gold Particles in the Witwatersrand Blanket Ore and Their Rate of Solution in Cyanide. Jour. Chem. Met. and Min. Soc. So. Afr., vol. 24, pp. 285–292, 1924.

is on but one side of the disc the edge is built up on that side. In cases where the rim shows on both sides, the disc at one time was covered on the two sides. Many of the cup-shaped particles frequently noted in the Snake River gravels by writers were probably formed in this manner and the coating later removed. The coating, whether clay or calcium carbonate, thickens toward the center of the disc and adds strength to the interior of the flake with the result that when it is rolled along and battered, the edges are bent over and built up.

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DISCUSSION AND COMMUNICATIONS

ANDALUSITE IN CALIFORNIA AND KYANITE IN NORTH CAROLINA.

Sir:—Two interesting papers recently published in this journal describe the occurrence of andalusite [1] in California and of kyanite [2] in North Carolina. These aluminous silicates provide several petrological puzzles which have not yet been fully appreciated. One of the greatest deficiencies in geology is that the investigator has to set a limit to the scope and area of his inquiry —and often the explanation of his problem lies, all unwittingly to him, just beyond the focus of his inquiry or beyond the picture of his map. In my own case, problems of one month have often been solved to my satisfaction by what at first sight seemed irrelevant features gleaned at a later date from a distant area. In reading many papers in geological literature I have often felt that the scope of the inquiry has been too limited, that a little enlargement of method and area would often give a different picture, and that, above all, the field, *not* the laboratory, is the final court of appeal in geological decisions.

There are several peculiar features associated with the occurrences of the aluminous silicates—andalusite, kyanite and sillimanite—which have no illuminating significance individually, but when one realizes how constant a feature they are of these deposits, they have a collective importance. Notwithstanding my antagonism to sweeping generalizations in geology, I have become more and more impressed with the similarity of the ultimate origin of these aluminous rocks. I have studied occurrences

[1] Kerr, P. F.: Andalusite and Related Minerals at White Mountain, Calif. ECON. GEOL., vol. 27, pp. 614–643, 1932.

[2] Stuckey, J. L.: Cyanite Deposits of North Carolina. ECON. GEOL., vol. 27, pp. 661–674, 1932.

of kyanite and sillimanite in several parts of Northern India,[3] and especially over a belt nearly 100 miles in length in Singhbhum. Individual geologists mapping each area would justifiably arrive at different conclusions as to the origin of these minerals in their respective areas. Even in Singhbhum, where, over a belt continuous for nearly 100 miles, common sense suggests that kyanite must have had a similar origin in all the deposits, attention paid to individual deposits would justifiably lead to different ideas of their origin. For example, the association of topaz and tourmaline in many cases would suggest to some geologists that the kyanite was a result of pneumatolytic metamorphism. On the other hand, other kyanite deposits in the same belt show no such relation to pneumatolytic minerals.

Reading Mr. Kerr's paper on andalusite at White Mountain, and substituting kyanite for andalusite, I could provide Indian instances exactly duplicating his field and petrological descriptions;[4] yet other deposits in the same area as these duplicate occurrences show features forcing me to broader conclusions. On the whole, however, I am in complete accord with Mr. Kerr as to the ultimate source of the aluminous material.

On reading Mr. Stuckey's paper, I could exactly duplicate his descriptions with occurrences in India, and if I limited my view to these duplicates, I would accept such an explanation of metasomatic replacement of acid crystalline rocks, pegmatite dikes and quartz veins as correct. I cannot, however, agree with many of his descriptions, as for example, the criteria for determining replacement of quartz by kyanite (Fig. 2). To most geologists familiar with metamorphic rocks, the features seen in the figured section are independent of the *time* of crystallization. Crystal boundaries in metamorphic rocks are not evidence of sequence; they merely indicate the power of a mineral to assert its crystal

[3] Dunn, J. A.: The Aluminous Refractory Materials: Kyanite, Sillimanite and Corundum in Northern India. Geol. Surv. of India, Mem. 52, 1929.

[4] The country-rock shown in Fig. 11 of Mr. Kerr's paper could be duplicated from many deposits in India. There are several explanations of the structures illustrated in such a crushed rock, and one would have liked to see the complete evidence on which the diagnosis of a trachyte flow was based. Would a crushed arkose, or even a tuff, be equally sound?

boundaries relatively to adjacent minerals during metamorphism Hence, in petrological descriptions, the use of the term " crystalloblastic order " and not " order of crystallization." The casual use of the term " replacement " is also to be deprecated.

There are several permanent features of all the aluminous silicate deposits that I have examined or read of in the literature. They are all associated with highly aluminous rocks, whether the latter be schists or gneisses. They are all of a lenticular nature, or are segregations in the aluminous schists, or in quartz-schists or quartz-granulites associated with the schists. Rutile is always present in these deposits, except in a few instances where the latter forms kyanite-quartz (or sillimanite) veins. This rutile is *not* magmatic in origin, it is also abundant in the associated aluminous country rock—and in the same country rock at a great distance from the segregations. The rutile is an original constituent of the country rock.[5] Many deposits are entirely independent of granitic intrusions, and the metamorphism that gave rise to the kyanite in many cases can be definitely shown to have taken place long before intrusion by the granite. Indeed, some of these deposits occur as *inclusions* in the granite and are *intruded* by the latter. I have seen instances of solid masses of sillimanite and corundum intruded by granite. In most cases quartz-granulites or quartz-schists and often kyanite (or sillimanite) quartz-granulites (or schists) are associated as definite beds in the aluminous schists of the country rock, the whole forming a bedded series of metamorphosed sediments (commonly tuffs).

I have been driven to the conclusion that the pneumatolytic minerals are merely attendant features of these deposits, and that the source of the andalusite, kyanite or sillimanite is fundamentally independent of them and of the factors that gave rise to them. These factors are, however, in many cases, responsible for the accumulation of the kyanite etc. into segregation masses

[5] This, notwithstanding that I am now approaching the opinion that highly heated waters, plutonic or inherent in the schists, are responsible for a larger part of the mineral changes during regional metamorphism than many geologists would admit, especially in mica-schists.

or veins. In India, there is a close parallel in the mode of formation of mica-pegmatites and kyanite (or sillimanite) veins. The pegmatite veins which have given rise to India's mica industry occur essentially in mica-schists; their mica content has been derived, in my opinion, from the latter and not from the granitic source of the pegmatitic solutions. So with the aluminous silicates, the veins and masses occur only in rocks which already contain these minerals; there has simply been a re-sorting of the aluminous material under the influence of the solutions that permeated the country rock. I am, therefore, in complete agreement with the majority of Mr. Kerr's conclusions, but of Mr. Stuckey's conclusion of magmatic origin I cannot but feel sceptical, especially as it seems to me that much of the evidence provided is capable of an opposite interpretation. I am still unconvinced of the occurrence of any kyanite, andalusite or sillimanite of magmatic origin; all the instances of such in granites that I have personally seen have been due to absorption of schists and to hybridization.

J. A. DUNN.

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CALCUTTA, INDIA.

QUANTITATIVE MICROSCOPIC METHODS.

Sir: It is a pleasure to note in the March–April number of Economic Geology [1] the paper by Thackwell on quantitative microscopic methods, for I believe that the geologists and metallographers could well afford to investigate and use some form of graphic analysis in much of their work. Thackwell's paper deals almost exclusively with the use and advantages of the new Leitz integrating stage as attached to a Leitz petrographic microscope. He discusses in addition the method of counting grains and the use of the integrating eye piece, methods which are not as common today as they were.

Thackwell in his summary says a survey of the fields of geol-

[1] Thackwell, F. E.: Quantitative Microscopic Methods with Integrating Stage. ECON. GEOL., vol. 28, no. 2, March–April, 1933.

ogy, mineralogy, and metallurgy shows that the advantages in microscopic analysis have been well appreciated, and yet he makes no reference to the papers of Julien,[2] Williams,[3] Lincoln and Reitz,[4] and Johannsen,[5] where the uses of other methods are discussed.

Some years ago I became sufficiently interested to make extensive tests with an advanced student,[6] of the then available methods in respect to accuracy and speed. It appears that the older methods are quite comparable with the results of Thackwell with the more expensive Leitz equipment. Some of my results could be obtained in a shorter length of time than he indicates.

It seems to me that it would be wise to call attention to other equipment such as the Wentworth stage which will do exactly the same kind of work with the same precision and the same saving of time but at less expense.

The only real advantage I can see with the Leitz integrating stage over previously available instruments is that after a "run" across a slide the spindles return to zero automatically. The spindles on the Wentworth stage have to be turned back by hand. This can be done in 15 seconds. The setting of the Leitz stage for another run is done by a rack and pinion while the Wentworth device requires a simple sliding of the microscopic slide along between the slide clips by hand. Both instruments will accomplish this in the same time.

What petrologists, mineralogists, and metallographers want to know is the relative merits of the various methods and the attendant instruments. This Thackwell does not tell.

HAROLD L. ALLING.

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ROCHESTER, N. Y.

[2] Julien, A. A.: Bull. Geol. Soc. Amer., 11, p. 460, 1903.
[3] Williams, Ira: Amer. Geol., 35, p. 44, 1905.
[4] Lincoln, F. C., and Reitz, H. L.: ECON. GEOL., 8, pp. 120–139, 1913.
[5] Johannsen, Albert: Jour. Geol., 27, pp. 276–285, 1919.
[6] Alling, Harold L., and Valentine, Wilbur G.: Quantitative Microscopic Analysis. Amer. Jour. Sci., vol. XIV, pp. 50–65, July, 1927.

REVIEWS

Geology of California. By RALPH D. REED. Pp. 355; figs. 60; map. American Association of Petroleum Geologists, Tulsa, Okla., 1933. Price, $5.00.

Thirteen chapters constitute this book, dealing with, Geologic Provinces, Structure, Pre-Mesozoic, and each of the succeeding geologic periods, ending with a Summary and an appendix with geographic names.

This book is more than welcome to geologists, not only in California, but the world over. It gives a connected outline of the whole geological story of California, told in a clear and logical manner and in a pleasing way.

In addition to the large amount of published data available, there has been a greater mass of geologic information acquired in the State by oil companies and by individual geologists, during the last thirty years, that has never reached publication; very little of it has been used extensively in "an adequate interpretation of the problems of regional geology and geologic history." The author says: "In order . . . to see the problems of special districts in their broader relations, there seems to be a need for attempted syntheses like that presented in this paper. The Coast Ranges need to be considered as a whole, their problems to be studied in the light of the known geologic history of the rest of California and of western North America."

In a way, the title "Geology of California" is something of a misnomer. As the author states, "I have written the following chapters from the point of view of a Coast Range geologist, and have given most attention to post-Jurassic events."

Actually, half of the book is devoted directly to the Tertiary and Pleistocene and the balance is used in approaching or summarizing that subject. The reader becomes convinced that the focus of attention seldom leaves the Tertiary beds. Geologic events, before and since that period, are described largely on account of their relationship to and influence on the Tertiary formations. Furthermore, the subject of sedimentation and petrology of sediments as a means of interpreting the geologic history has been much emphasized and rather favored over other lines of reasoning.

The book is interesting, stimulating, and easy to understand. It is not

merely a compilation, but original thought and fearless personal interpretation are always in evidence. The author avoids controversy, but some of the worst mistakes in observation and in logic among other geologists are cleverly brought out, with a flavoring of the author's well-known humor.

A more complete discussion on pre-Jurassic history would have given greater satisfaction to the reader. A brief discussion of the various metallogenic epochs would have also helped to broaden the scope of this scholarly work.

The author, however, has been successful in following out his aims in writing the book, for he has furnished "a sketch of the stratigraphy, structure, and geologic history of California, with particular reference to post-Triassic events in the coastal province" in his well-organized and well-summarized chapters; he has brought "into relief some of the major unsolved problems of California geology"; and has given constructive suggestions as to how these problems may be solved, especially in Chapter XIII. Also, he has furnished "geologists in general with a simple introductory account of the present status of geologic work in this State" especially as regards the work of the petroleum geologist, whose success has outstripped all others in detail and completeness. The author says: "I have omitted discussions of oil accumulations, but have discussed the problems with which oil geologists, as well as many other geologists, are ordinarily concerned." He further states: "In accordance with my interest in the problems of oil geology, I have given much attention to the Miocene epoch, and particularly to the nature and origin of the Monterey shale, the most interesting rock formed on the West Coast during that epoch. My present views as to the origin of this formation are to some extent new, though not unrelated to others that have been held previously. They involve a conception of middle Miocene diastrophism that is sharply opposed to the ideas that were suggested a few decades ago and have since been widely quoted and believed." About a third of the book is devoted to the Miocene.

To the reviewer, the paragraphs on "paleogeography" are by far the greatest contributions of the book. The introduction of the names *Mohavia, Salinia,* and *Catalinia* for ancient land areas proves useful in simplifying the discussions. The last two names are for peninsulas that "were important paleogeographic provinces during different stages of the Cretaceous and Tertiary periods." Mohavia includes the region of the Sierra Nevada as well as the Mohave Desert.

The author's views on the three Franciscan areas (Northern, Central, and Southern) and their relationship to structure as well as their contributing value to the sediments of the overlying beds are interesting. He says: "An important constituent of most Franciscan areas is serpentine,

derived from peridotite and similar basic rocks. Partly because of the prevalence of this rock, the series as a whole yields to deforming forces much more readily than the Granitic Basement. Extreme complexity of structure is almost a distinguishing feature of the Franciscan. Where it is overlain by even a thin cover of sediments, the latter also yield easily to deforming stresses. Folds of many types and sizes are therefore characteristic of areas underlain by the Franciscan."

The metamorphic and granitic rocks of Mohavia and Salinia were the greater contributions to the sediments prior to the Temblor (Lower Miocene). Feldspathic grains in the sediments seem to be dominant throughout the whole post-Triassic column regardless of differing climatic conditions inferred from the fossils and other criteria. Former views concerning aridity of the Tertiary, based partly on the presence of unweathered feldspar grains, are shown to be in error.

In using both lithologic and fossil evidence for inferring climatic conditions, he shows his respect for paleontology, but apparently feels that there is much disagreement among the paleontologists.

Three "important diastrophic periods" are tabulated by the author as follows: (1) Late Jurassic (earlier in the Coast Ranges?); (2) Middle Miocene; (3) Pleistocene. In the first there was "intense folding in the Sierra Nevada," in the second "local folding in the Coast Ranges," and in the third "strong folding and severe faulting." The author states: "Along the Pacific Coast the Pleistocene seems to have been an epoch of greater diastrophic changes than any other that has occurred since Middle Mesozoic. Most of the great faults of California may date from the Pleistocene, and many large folds, such as the Kettleman Hills and Ventura anticlines, are certainly no older. During a part of the epoch, furthermore, much or all of the region seems to have been broadly uplifted to a height some thousands of feet greater than its present elevation."

The present physiographic condition of the country is shown to be entirely different from anything which has preceded it. A chart is given, showing "paleogeographic maps of Cretaceous, Vaqueros, Upper Miocene, and Pliocene." In consideration of present-day physiography, a list, map and discussion are presented, showing twelve "Provinces of California." They are given as follows: (1) Continental shelf and island area; (2) Transverse Ranges; (3) Southern Coast Ranges; (4) Northern Coast Ranges; (5) Klamath Mountains; (6) Sierra Nevada; (7) Great Valley; (8) Peninsular Ranges; (9) Colorado Desert; (10) Mohave Desert Region; (11) Modoc Lava Plain; and (12) Cascade Range.

In discussing structure, much importance is placed on the position of the three great Franciscan areas in contrast to the areas underlain by granitic rocks. "Some important faults of California" are shown on a

map as follows: San Andreas, Hayward, San Jacinto, Nacimiento, Elsinore, Garlock, and Sierra Nevada. The Mother Lode is also shown. Besides, a long line indicates the axis of the Great Valley syncline, following near the west side of the Sacramento and San Joaquin Valleys, where accumulation of sediments is the thickest. Between the Nacimiento and San Andreas faults is an area said to contain no Franciscan rocks. To this area is given the name Salina, frequently featured in the study of geomorphology of the past.

Faulting is considered to have been somewhat overworked by many geologists. Detailed mapping has had a tendency to eliminate some of the faults previously considered to have been of major importance. Unconformities are not taken very seriously by the author, because, as he states: "When a geologist or paleontologist decides that a series of beds should be treated as a formation, he looks for unconformable contacts between it and those adjacent to it, and almost always finds them."

With few exceptions, the book appears to be quite free of inaccuracies in its statements, even though it covers such a broad field of study. Recent work, such as that on the lower Cretaceous and uppermost Jurassic, has affected some of the statements, but most of these have been corrected in added footnotes. A few, not many, typographical errors are in evidence. The reader may be a little skeptical about wholly believing some of the sections and diagrams, which have been drawn in a rather positive manner, but in many cases are adapted from other geologists' work. The verbal expressions of the author's own views, put in his own language, are by far the best part of the book and should be read by everyone interested in the geology of California.

OLAF P. JENKINS.

CALIFORNIA STATE DIVISION OF MINES,
SAN FRANCISCO, CAL.

Angewandte Geophysik für Bergleute und Geologen. By H. REICH. Teil. I. Pp. 151, illus. 74. Akad. Verlagsgesellschaft M. B. H., Leipzig, 1933. Price, 12.50 M.

This little book, which will be followed by a second part, is intended for miners and geologists who wish to become sufficiently acquainted with the principles of geophysical methods to enable them to interpret their results. It discusses, with a minimum amount of mathematics, the application of these methods to the investigation of tectonics and the discovery of the extent of certain types of ore-bodies, and explains the manner of using them by illustrations drawn from the reports of geologists in many parts of the world.

Part I deals with the use of gravity, magnetic, and seismic methods in the study of tectonics and the distribution of sedimentary deposits, such as

petroleum, coal, iron ores, placers, etc. Part II will give their use in the outlining of magmatic ore-bodies, in quarry study, and in the search for underground water.

The book is clearly written and should serve as a satisfactory introduction to a general knowledge of geophysical methods, and the results that may be expected from them.

W. S. BAYLEY.

Igneous Rocks and the Depths of the Earth. By R. A. DALY. Pp. 598, figs. 190. McGraw-Hill Co., New York, 1933. Price, $5.00.

This volume is a revision of "Igneous Rocks and Their Origin" (Daly, 1914), but so complete a revision that its title has also been changed. Only a small part of the older text has remained intact; chapters have been rewritten, new ones added, and many new illustrations included. The result is essentially a new book. The revision includes new data revealed by geophysics, vulcanology, and experimental petrology. New opinions are set forth relating to magmatic stoping, abyssal melting, and magmatic conditions of early pre-Cambrian. Some new terms appear. Part I deals with "Leading Facts"; under Part II, "General Theory," the major problems of petrology are discussed, and Part III is a discussion of the various rock clans.

The book is delightfully written, is well illustrated, and contains a wealth of information and speculation.

BOOKS RECEIVED.

BY DAVID GALLAGHER.

The Limestones and Marls of Minnesota. By C. R. STAUFFER AND G. A. THIEL. Pp. 193, figs. 93. University of Minnesota Press, Minneapolis, 1933. Price, $1.00.

A detailed description of the occurrences of limestone, dolomites and marls in Minnesota; including their nature and origin and a statement of their uses. Part I, on limestones and dolomites, is by Stauffer; Part II, on marls, by Thiel. The discussion on the origin of marl, while mainly a compilation, affords an excellent summary of the subject.

The Chromite Deposits of the Eastern Townships of the Province of Quebec. By B. T. DENIS. Pp. 106, figs. 13, pls. 5, map. Quebec Bureau of Mines, Ann. Rept. for 1931.

This report contains information on the occurrence and development of chromite deposits that has accumulated since the report of Cirkel in 1909. It includes a summary of views on their origin, descriptions of now known occurrences, and statements of their economic importance, also a colored map of deposits.

Studies of Geophysical Methods, 1930. By A. S. Eve, D. A. Keys, L. Gilchrist, and A. H. Miller. Pp. 118, figs. 51. Canada Geol. Surv. Mem. 170. Ottawa, 1932. Record of investigations at Mammoth Cave, Kentucky, and Caribou Lake, Quebec.

Zinc and Lead Deposits of Canada. By F. J. Alcock. Pp. 406, maps 1, pls. 8, figs. 34. Canada Geol. Surv., Econ. Geol. Series No. 8, Ottawa, 1930. Price, 75 cts. Comprehensive scientific and theoretical treatment, together with descriptions of the occurrences in Canada, price and production statistics, and summary of World occurrence.

Investigations of Fuels and Fuel Testing, 1930 and 1931. Pp. 166, pls. 3. Canada Dep't Mines, Mines Branch, No. 725. Ottawa, 1933. Eleven papers by various authors on solid fuels, natural gas, and liquid fuels.

Transactions of the Institution of Mining and Metallurgy. General and Personal Index, Vols. XXXI to XL, 1921–1931. By G. F. Bird. Pp. 143. Published by the Institution, London.

Les Constituants des Charbons, Leur Influence sur Quelques Propriétés Industrielles. By M. Legraye. Pp. 152, pls. 12. Bibliothèque Scientifique Belge, Georges Thone, Éditeur. Liège, 1933. Price, 18 francs.

Geology and Oil Possibilities of the Moab District, Grand and San Juan Counties, Utah. By A. A. Baker. Pp. 95, pls. 11, figs. 3. U. S. Geol. Surv. Bull. 841. Washington, 1933. Price, 50 cts. Showings of oil and gas, but no commercial production. Much geological information and maps.

Imperial Institute, Annual Report, 1932. By Wm. Furse, Director. Pp. 55, figs. 1, pl. 1. London, 1933. Account of the wide and ever increasing scope of the Institute's activities.

Geology of the Central Part of the Mazoe Valley Gold Belt. By R. Tyndale-Biscoe. Pp. 120, pls. 13, geologic map in color. Southern Rhodesia Geol. Surv. Bull. 22. Salisbury, 1933. Price, 4s. General geology, stratigraphy, petrology, structure, and economic geology; numerous rock analyses.

Einige neuere Anwendungen der Geophysik bei Talsperren und Grundwasser-Problemen. By C. A. Heiland. Pp. 24, figs. 8. Geologischen Rundschau, Band XXIII–a, Salomon-Calvi-Festschrift.

Clay and Shale Resources in Southwestern Pennsylvania. By H. Leighton and J. B. Shaw. Pp. 190, figs. 16, tables 27, geologic map in color, scale 1:380160. Penn. Topog. and Geol. Surv. Bull. M–17. Harrisburg, 1932. General treatment, plus descriptions and tests of all clay occurrences.

Le Poids Spécifique et la Composition Chimique de la Becquerelite et de la Schoepite. Les Minéraux du Gite Cuprifère de Tantara. La Vandenbrandeite, un nouveau Minéral Uranifère. By A. SCHOEP. Pp. 31. Annales du Musée du Congo Belge, A–I. Vol. 1, No. 3, Bruxelles, 1932.

Recherches Lithologiques sur des Roches Carbonatées du Katanga. By A. SCHOEP, A. L. HACQUAERT, AND A. GOOSSENS. Pp. 103. Annales du Musée du Congo Belge, A–I. Vol. II, No. 1. Bruxelles, 1932. Detailed petrographic and chemical studies; well illustrated.

Limestone Deposits of Tanganyika Territory. By F. OATES. Pp. 120, maps and diagrams 7. Geol. Survey of Tanganyika, Bull. 4. Dar es Salaam, 1933. Price, 5s.

Metal Resources of New Mexico and Their Economic Features. By S. G. LASKY AND T. P. WOOTTON. Pp. 178, figs. 4, maps 2. New Mexico School of Mines, Bull. 7. Socorro, 1933. Summary of metal resources, descriptions of all mining districts and individual mines, production, uses, marketing.

College Textbook of Geology (Chamberlin and Salisbury), Part I, 2nd edit. By R. T. CHAMBERLIN AND P. MCCLINTOCK. Pp. 445, figs. 376. Henry Holt & Co., New York, 1933 (Aug.). Price, $3.00.

A revision and expansion of the 1927 edition of the same book. Subject matter brought up to date; new material added; many new illustrations; addition of block diagrams and more colored maps. A brief, well rounded text.

Le Graphite. By R. SAUFFRIGNON. In two parts: (1) Etude Economique, pp. 58, tables 5, figs. 16, uses and production; (2) Etude Technique, pp. 51, figs. 9, properties, geology, mining, and treatment. Mines Carrières, Paris, 1933. Price, 10 fr. each.

Geology of Sirohi State, Rajputana. By A. L. COULSON. Pp. 188, 11 pls. showing 30 figs., 11 figs., geologic map in color, scale 1″ = 4 miles. India Geol. Surv. Mem. vol. LXIII, Pt. 1. Calcutta, 1933. Price, Rs 7–8 or 12s. A region of acid and basic intrusives into Archean and Purana stratified rocks.

Gold Outputs and Mining Activity of Southern Rhodesia, 1907 to 1932. By S. B. NORRIS. Pp. 20, graphs 2. Southern Rhodesia Geol. Surv. Bull. 25. Salisbury, 1933. Price, 4d. Statistical.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SCIENTIFIC NOTES AND NEWS

D. M. Davidson is returning from Canada, where he has been engaged in gold prospecting, to resume geological work at Mufulira mine, Northern Rhodesia, which is to be re-opened this year.

R. W. Brock, of the University of British Columbia, has completed his geological survey of the island of Hong Kong for the British Government and has returned to Vancouver. The University of Hong Kong gave him an honorary LL.D. degree.

Frederick G. Clapp has returned to the United States and is at Suite 1380, 50 Church Street, New York City.

T. Watanabe, mining engineer of Osaka, Japan, has been visiting mining districts in the western United States.

H. A. Buehler, State Geologist of Missouri, is investigating the commercial possibilities of fuller's earth deposits in southeastern Missouri.

Arthur Notman, of New York City, is assisting the National Recovery Administration as adviser on non-metallic minerals.

Arthur Keith has been engaged in the study of dam site problems at Cove Creek for the Government in connection with the Tennessee Valley project.

Hoyt S. Gale, formerly geologist with the Gulf Oil Corporation in California, is to make a detailed geological study of the Hawaiian Islands for the U. S. Geological Survey.

The Royal Ontario Museum, Toronto, held an Official Re-opening reception on October 12.

Fraser D. Reid, consulting engineer for Eldorado Mine, visited their silver-radium properties at Great Bear Lake in July. He has been elected president of the Ontario Mining Association for 1933–4.

The fall New England Intercollegiate Geological excursion was held this year on October 13 and 14 at Williamstown, Mass., and vicinity. A study was made of Taconic rocks and structure, under the guidance of Professor H. F. Cleland, L. M. Prindle, and E. B. Knopf.

The Society of Economic Geologists will hold its annual meeting in Chicago, December 28–30, in conjunction with the Geological Society of America. Papers that are to be presented at that time should be sent to the chairman of the publications committee, B. S. Butler, University of Arizona, Tucson, Ariz.

A. G. Burrows, Provincial Geologist of Ontario since 1925, died at Toronto on Sept. 3, aged 56. Dr. Burrows ranked high in his profession for notable contributions in the field of scientific and geological knowledge.

Frank R. van Horn, professor of geology and mineralogy in the Case School of Applied Science, Cleveland, Ohio, died on August 1, aged 61 years.

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